Chapter 4 – COMMON MILITARY TASK: DIGGING

by

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ABSTRACT

Digging trenches, filling sand-bags, and shovelling debris have been shown to be common military tasks (CMTs) during land-based, military operations throughout the Armed Forces of NATO. The role of digging and shovelling has been considered to be a critical requirement of these CMTs. Screening protocols have been developed that reflect the physical demands of such critical requirements and which enable the physical abilities of new recruits and incumbents alike, to be assessed against the same criteria that have been shown to best-predict CMT performance (i.e. criterion-tests). A popular approach in the development of valid screening protocols has been to design simulations that were representative of the most physically demanding digging CMTs (i.e. content-based). However, the reported reliability of such protocols, when screening for digging-based abilities, has been variable (ranging in r^2 from 0.81 (worst) to 0.99 (best)) and lacked adequate agreement with CMT performance (ranging in r^2 from 0.14 (worst) to 0.72 (best)). Association with lower back injuries and the lack of validity as discriminator tests have often resulted in the withdrawal of digging-based tests from screening protocols. However, research to develop valid methods of assessing digging performance continues and this chapter provides a summary of developments from the early 1900's to research programmes that were active during 2005 within the NATO membership.

4.1 INTRODUCTION

Members of the HFM-080 RTG-019 were asked to review the research that had been conducted concerning common military tasks (CMTs) and the role that these tasks had placed on the development of screening protocols to assess physical fitness for effective performance on military operations. The RTG agreed to compile a report to summarise its findings. Digging trenches, filling sand-bags, and shovelling debris have been shown to be CMTs during land-based, military operations throughout the Armed Forces of NATO. Furthermore Stickland 1995 concluded that:

> *'Manual excavation will continue to play an important role in the construction of field defences … even the wider scaling of digging plant equipment will not remove the need for large numbers of military personnel to manually dig trenches on the battlefield'.*

Screening protocols have been developed that reflect the physical demands of digging (and shovelling) and which enable the physical abilities of new recruits and incumbents alike, to be assessed against the same criteria that have been shown to best-predict CMT performance (i.e. criterion-tests). A popular approach in the development of valid screening protocols has been to design simulations that were representative of the most physically demanding digging CMTs (i.e. content-based). This chapter provides a review of the literature concerning digging CMTs and discusses the research that has been conducted to develop valid methods of assessing digging performance within the NATO membership.

4.2 OBJECTIVE

This chapter was intended to:

- Provide a review of the literature concerning manual digging and shovelling tasks;
- Identify CMTs in which digging or shovelling was required; and to
- Summarise the research that had been conducted within NATO to assess the ability of military personnel to conduct these CMTs (i.e. physical fitness screening protocols).

4.3 THIS REVIEW: SCOPE AND FOCUS

This chapter was concerned solely with non-mechanised methods of material excavation (i.e. digging and shovelling CMTs[1]) that have been used (or implicated) in the development of protocols to assess physical abilities that were essential for effective task performance. Furthermore, only those data that have been rated as *'unclassified'* and which were obtained by the search mechanisms described in Table 4-1 have been discussed. The focus for this chapter was on research that bore relevance to manual excavation tasks performed by the Armed Forces, and the scope was limited to NATO and those participants within the *Partnership for Peace.*

Table 4-1: Method and Criteria Used to Review the Literature Concerning Manual Digging Tasks

Serial	Source	Search Criteria (Keywords)
1	Web*CAT*® *STRSI*	*Authors:* Bensel, Haisman, Rayson, van Dijk, Jaenen, Lee, Knapik, Sharp, Hodgdon, Vogel, Gledhill, Deakin *Keywords:* Digging, entrenchment, shovel, shovelling, trench, foxhole, excavation, manual handling, materials handling, military, NIOSH, RPE, spade, design, occupational tasks, entrenching, shell scrape
2	Web of Science	
3	Defence Reports Abstracts MOD Edition (UK) 2000 – 2004	
4	NATO HFM technical reports database http://www.rta.nato.int/Abstracts.asp?RestrictPanel=HFM	
5	Science and Technology Information Network (USA) http://www.dtic.mil/dtic/prodsrvc/stinet.html	
6	PUBMED (Medline) http://www.ncbi.nlm.nih.gov/entrez/query.fcgi	
7	NATO HFM-080 RTG-019 E-mail to members: request for information	
8	NATO HFM-080 RTG-019 meeting #1 (Warendorf, Germany, Jun 03) Proceedings CD (Research Update for NATO members)	
9	NATO HFM-080 RTG-019 meeting #2 (Austria, Jun 04) Proceedings CD (Research Update for NATO members)	
10	Biomech-L internet mailing list	
11	Sports science interest group http://sports.groups.yahoo.com/group/sportscience/	
12	Health and Safety Labs, UK	
13	Health and Safety Executive, London	
14	Information services, Royal Engineers School of Engineering, Gibraltar Barracks, UK	

[1] Excavation involving explosives or powered vehicles/tools have been excluded from this chapter on the basis that such methods tend not to influence the design of physical fitness tests or standards that have been used throughout the military.

Serial	Source	Search Criteria (Keywords)
15	Defence Standards (DEFSTAN) http://www.chots.mod.uk/defence_standards/	
16	Human Sciences Research database, Research Acquisition Organisation, UK	
17	IEEE *Xplore*® unclassified network	
18	Taylor & Francis online journals database (*includes:* Applied Ergonomics, Ergonomics, etc.)	
19	Individual Deployment Training course manual, RAF Innsworth, UK	
20	Science Direct e-journals http://www.sciencedirect.com/science?_ob=JournalListURL&_update=y&_auth=y&_acct=C000056583&md5=15afcab5847a4295130fabec91c03cfc&subjColl=all&stype=title&type=subscribed&x=11&y=7	
21	MoD Engineers Disk, Quick Finder http://corporate/mod/bgodad7/disk5/nav/qfind/qwk_find.htm	
22	NATO STARNET website http://starnet.rta.nato.int/	

4.3.1 Searches Conducted and Criteria Used

The methods and criteria that were used to obtain the information that has been discussed in this chapter have been summarised in Table 4-1.

4.4 DIGGING AS A BONA FIDE OCCUPATIONAL REQUIREMENT

A Bona Fide Occupational Requirement (BFOR) has been defined by the Canadian Human Rights Act (1982) as a condition of employment which is enforced with the belief that is it essential for safe, efficient and reliable job performance. The importance for an employer to establish a BFOR has been evident within case law when assessing the legitimacy of screening programs to select new employees or to assess incumbents for their fitness to work. The BFOR affords the benefit of enabling employers to match employees to the work that they are capable of performing, and to define specific training requirements in order to best prepare their staff to meet the demands of their occupational role.

Canadian Human Rights Legislation (CHRC, 1985; CHRC, 1988) identifies three key factors (a to c) which underpin the existence of a BFOR:

a) Classification of the essential components of the job;

b) Requirements for safe, efficient and reliable performance of the job tasks; and

c) A means of assessment to determine whether an employee has the capability to meet the job requirements.

The policy in Canada for the development of a BFOR required that the evidence used to develop a BFOR were objective and supported by expert opinion and scientific evidence when available. However, where it can be demonstrated that the existing work environment could be changed to accommodate an individual's ability to perform the job, then a BFOR does not exist. Subsequently a BFOR is not a static condition, and it may change in time with advances in technology. A pre-requisite in the process to establish the

validity of screening military personnel for their ability to perform digging and shovelling tasks must be based upon a BFOR. In order to establish a valid screening protocol to assess military personnel for their ability to perform digging and shovelling tasks it must be shown first that digging (and shovelling) fulfils the requirements of a BFOR.

Digging was found to be the eighth most frequently conducted task of all the physically demanding tasks (from a table of 20 physical tasks) within the US Army. During a study to develop criterion performance tasks for the purpose of establishing 'physical abilities' standards for entry to the US Army, Myers et al., 1984 analysed 1,999 critical tasks across all job categories and reported digging to occur in 1% of all US Army job tasks that were considered to incur a 'very heavy physical demand' (on a scale of light to very heavy), and 2% of all moderately heavy tasks.

4.4.1 Military Relevance (Infantry and Engineers)

Survivability is a term that has been used throughout the Armed Forces of NATO to describe the fundamental aspects of protecting military personnel, weapons and materiel from enemy and detection systems. Digging has been universally identified as a fundamental skill that is required by tasks which enhance military survivability (ATP-52(A) 1997). A number of tasks have been proposed within the context of survivability (NATO 2001) which require manual digging, and these include:

- Preparation and construction of field fortifications;
- Camouflage, concealment and deception; and
- The clearance of fields of fire.

Stickland 1995 suggested that; 'the better your digging, the better your chance of survival'. The soldier, when under fire, very rapidly learns or re-learns the enormous value of a 'good' hole in the ground, as a means of protection. The hole in the ground may take many forms, from the "natural opening shell crater, ditch or gully, to a carefully constructed bunker system". The main protection element of the hole is that provided by the earth itself. This is reinforced by the low profile and subsequently reduced target area. Each type of hole will serve a purpose. The individual on the ground needs to be aware of the local threat to allow the correct defensive measures to be taken considering the length of time the area is liable to be occupied and for what purpose. The effectiveness of the hole means that any alternative to digging is a second choice.

As society has advanced and machines replace manual labour everywhere, the number of people with previously learnt digging skills joining the Armed Forces has reduced dramatically. Lack of basic skill or training can lead to inefficient excavation, poor trench structural properties or medical problems such as lower back compression injuries for the individual performing the digging task. Therefore hand digging should be included at an early stage in the training programme (Stickland 1995).

Hand held power tools have a place in the military inventory for many tasks. However, their benefits for trench construction are limited by the signature that is evident when using them, and the effort required just to move the tool(s). This energy would in most cases be more effectively used with the pick and shovel. Only the hardest of soils requires the use of the mechanical breakers (Stickland 1995).

Wright 1993 reviewed the field manuals and working procedures for soldiers in the British Army, and identified a number of digging[2] and shovelling tasks that were required within the basic military role. These included the actions of digging and shovelling to:

[2] For the purpose of this review *digging* has been defined as the act of penetrating or loosening a material (e.g. breaking up earth in a trench) when using a digging tool, whilst *shovelling* is the act of transporting the loose material from its original position to an alternative location whilst using a spade of shovel.

a) Construct shell scrapes;

b) Build trenches (of various shape, size and functional purpose);

c) De-turf grassed areas;

d) Place explosives;

e) Clear debris; and

f) Fill sand-bags.

These tasks have also been identified by a number of researchers and summarised in Table 4-8. Furthermore Wright 1993 defined the equipment and the methods that were used by the British Army to dig in various types of terrain (hard rock, gravel, sand, etc. (See Appendix 4A-1)).

The media have reported a number of military operations during which the use of digging and shovelling tasks were shown to have been essential to the success of each mission. Such reports included operations undertaken by Canadian forces in:

a) Manitoba (clearing debris with shovels, digging trenches, setting up shelters, building dykes and filling sand-bags during the floods);

b) Rwanda (1994 – 95);

c) Bosnia, Croatia and Cambodia;

d) Saguenay (entrenchment dig and filling sand-bags); and

e) Ontario (filling sand-bags during an ice storm).

Data from the British military have shown that UK Armed Forces have dug trenches, filled sand-bags, constructed sangars, dug wells and sanitation, and cleared debris using shovels as part of their operational role all over the World (including Mozambique (1991 – 92), FRY (1993 – 95), Montserrat (1996), Kosovo (1999), East Timor (1999), and Kuwait and Iraq (2003+)).

Commonplace in military training and policy manuals throughout the Armed Forces within NATO is the reminder to service personnel that despite their current specialisation or trade, in the event of an emergency, and when circumstances dictate, they are all soldiers, sailors or airmen first and foremost. Accordingly all operational personnel within the Armed Forces who are issued with a weapon are expected to be able to perform the basic skills (Common Core Skills, Survive to Operate, etc.) that have been identified as bona fide occupational requirements (BFOR). In order to establish a BFOR (Constable and Palmer 2000) several Armed Forces within NATO have developed 'Mission Essential Task Lists (METL)' which can be used to define selection and maintenance criteria (Nevola et al., 2003a) and to match training to the specific 'needs' of tasks within the operational role.

Three of the 14 core operational tasks that were defined as a BFOR for RAF combined incident teams involved digging or shovelling actions (Nevola et al., 2003b), and were conducted for (mean (1SD)) 16.5 (14.5) % of the total duration of these core operational tasks. Digging was identified as one of four critical tasks that were required by land-based personnel within the Netherlands military services, during a project to develop criterion-based physical fitness standards (MOMRP 1999).

During a project to develop a bona fide Minimum Physical Fitness Standard (MPFS) for Canadian Forces personnel[3], the ergonomics research group at Queen's University (Canada) identified an entrenchment dig task as one of the five most common tasks applicable to military duty. To establish the five tasks Deakin et al., 2000 conducted a review of the literature and the media which related to military exercises during

[3] This was intended to comply with the requirements of the Canadian Human Rights Act.

peace keeping and emergency duties, they re-assessed the findings of their earlier studies (dated 1988) and consulted an expert advisory panel. Following this process the entrenchment dig was considered to be 'representative of military tasks performed by the Canadian Forces today'.

It is known that soldiers in the US Army dig foxholes to protect themselves from enemy fire. Eighteen different military occupational specialities (MOS) identified digging as a critical task in the effective performance of their role. Blade loads that were reported for these MOS' ranged from 4.5 to 15.0 kg and the volume of material that was dug ranged from 1.0 to 55.0 m^3 (Sharp et al., 1998).

During a study in which 212 trained personnel from the US Marine Corps were asked whether they had operational experience of digging with an entrenching tool and a conventional shovel (Davis et al., 1986) it was shown that all (100%) had used an entrenching tool to dig in jungle operations, and 7% had used a conventional shovel during amphibious operations[4].

4.5 INTENSITY AND DURATION OF COMMON DIGGING TASKS

The digging tasks reported in the literature involve shovelling 0.5 to 1.0 m^3 of sand, earth or pea gravel from one container into another (Sharp et al., 1998). These tests tend to be poorly correlated with measures of physical fitness (Visser et al., 1996). Future development of an effective and reliable means of assessing digging and shovelling performance must understand the factors that underpin the physical demands that are imposed when conducting such tasks. Paragraphs 4.5.2 to 4.5.29 discuss those factors that influence the physical demands of tasks that involve digging and shovelling. The factors that have been reviewed are limited to those that have been reported in the media that were searched and listed in Table 4-1. It is likely that not all of the factors that would be expected to influence the physical demands of digging have been addressed. However, the review is intended to reflect the level of understanding that was evident at the time that this chapter was written (2005) and upon which extant physical screening protocols have been based. For the purpose of this review, evidence from the literature was sought with which to consolidate the body of knowledge that described (at the time of writing this chapter) the intensity and duration of digging (and shovelling) (Section 4.5), the physiological requirements for completing such tasks (Section 4.8), tests that have been proposed to assess task performance (Section 4.9) and physical training that may improve an individual's ability to complete such tasks (4.10). Sections 4.6 and 4.7 have summarised the common military tasks which concerned digging (and shovelling) and identified the equipment that has been used by NATO forces to complete such tasks.

4.5.1 Results of Laboratory and Field Studies

Scientific analysis of digging tasks were first reported in the open literature in the early 1900's (Taylor 1913) following research at the Bethlehem Steel Works in 1898. By simply allocating shovels of different blade sizes to work with low- or high-density materials (i.e. rice coal and iron ore respectively) it was possible to standardise the weight of the blade load to a manageable 9.7 kg. This action alone enabled 140 men to complete the task that had previously taken more than 400 men to complete with the former single-sized shovel that had been used for all materials. An impact such as this, with the financial implications that ensued concerning occupational performance and total productivity, provided the momentum for further research.

Developments in manual digging strategies have focused upon re-designing equipment to reduce the energy cost incurred by the individual performing the task. A number of design features which may influence the energy cost (or efficiency) of digging with a shovel (or shovelling) have been investigated. Such features include:

[4] It was also shown that 64% of US Marines had used an entrenching tool during cold climate operations, 50% during desert operations and 14% during amphibious operations, whilst only 22% had used a conventional shovel in the jungle, and only 14% had used the shovel in desert operations.

a) The weight of the shovel;

b) Handle type and length;

c) Lift angle; and

d) Blade size, shape and thickness, etc.

However, only a few of these features (and other proposed influential factors) have been investigated under controlled conditions. Consequently the results that have been reported in the available literature have been inconclusive. Some of the prime factors that have been known to influence shovelling task performance such as[5]:

i) Shovelling rate;

ii) Blade load;

iii) Throw height;

iv) Properties of the material in which to dig;

v) Throw distance; and

vi) Posture (or technique) have been generally well reported.

The following sections (4.5.2 to 4.5.9) provide an account of those studies which have attempted to address these prime factors, and which also discuss the research that concern the less well understood effects of the shovel's design features.

4.5.2 Throw Height and Throw Distance

The higher that the blade load must be raised above the surface from which it was dug, the greater the energy expenditure (Freivalds 1986). Spitzer 1950 showed that by reducing the throw height from 2.0 m to 0.5 m effectively reduced the rate of energy expended during a repetitive shovelling task by 50%. Stephenson and Brown 1923 concluded that shovelling performance was 'reasonably constant' up to a throw height of 1.3 m. They recommended 1.0 to 1.3 m as a throw height that should be considered to be 'acceptable' for a prolonged shovelling task. However differences in the way data were analysed and the use of alternative performance criteria may explain the large variance that was evident when attempting to compare the results reported by different investigators[6].

As expected, Spitzer 1950 found that the further the distance that material was thrown from the original point at which the material was dug, the greater was the associated energy cost (Table 4-2). Distances greater than 1.22 m were found to incur significantly greater energy costs than for those thrown <1.22 m (horizontal distance). Freivalds 1986 considered these results together with the data of Stephenson and Brown 1923 and concluded that the optimum throw distance (in terms of the maximum distance that a specified volume of material could be displaced at a given shovelling rate without incurring a significantly greater energy cost) was 1.2 m.

[5] Clarification of the terms and phrases that have been used in this chapter to describe digging and shovelling has been provided within Figure 4-5.

[6] Some studies have used the time taken to displace a given volume of material as the measure of *'gross efficiency'*, (so any factor that improved the rate at which material could be displaced was considered to be 'more efficient' by some researchers (Wenzig 1928, 1932)) whilst other studies have considered a low *energy cost* attributed to the shovelling task as the prime success criterion (i.e. energy economy). Between studies the specification and conditions of the shovelling task differs. No standard digging protocol has been reported against which isolated factors can be compared and assessed.

Table 4-2: The Effect of the Blade Load, Throw Distance and Throw Height on Energy Expenditure (KJ•min^{-1}) Observed for Every 100 kg of Material Shovelled (Adapted from Spitzer 1950)

	Throw Distance (m)								
	1.0			2.0			3.0		
	Blade Load (kg)								
Throw Height (m)	*5.0*	*7.5*	*10.0*	***5.0***	***7.5***	***10.0***	***5.0***	***7.5***	***10.0***
0.5	21.7	18.9	19.5	32.5	27.8	26.6	48.7	36.5	32.5
1.0	30.8	24.4	25.4	41.8	36.5	34.4	53.1	41.8	39.0
1.5	39.0	30.8	32.5	48.7	41.8	41.8	53.1	45.0	45.0
2.0	41.8	34.4	39.0	53.1	45.0	48.7	58.5	45.0	48.7

4.5.3 Blade Size and Shape

The size of the blade (of the shovel) that afforded the best results with respect to the time taken to displace a given volume of material, was found to be dependent upon the density of the material that was being shovelled.

A large blade size was preferable (in terms of energy economy and shovelling efficiency) when digging in materials of low density (Kirsch 1939). Lehmann 1953 provided recommendations for choosing the blade size of a shovel (Table 4-3).

Table 4-3: Recommended Blade Size of Shovels Used to Dig Based upon the Density of the Material Displaced (Taken from Lehmann 1953)

Material Displaced (Shovelled)	Density of Material (kg·m^{-3})	Blade Size (m^2)
Iron alloys	3700	0.05
Iron ore	2500	0.07
Sand, dirt (moist)	2000	0.09
Basalt	1800	0.09
Sand, dirt (dry)	1500	0.12
Coal	800	0.18
Coke	400	0.20

Kirsch 1939 and Vennewald 1939 studied the effect of the shape of the blade on the time taken to dig a specific volume of material. A square, flat blade with raised edges was reportedly best employed for digging coarse-grained material, whilst a round pointed, curved blade with slightly raised edges was found to be best with sand and soil. These results were consistent irrespective of the thickness of the blade when comparing shovels of the same weight.

4.5.4 Shovelling Rate and Blade Load

The results of several studies tended to agree (Kommerell 1929, Lehmann 1953) that for a given rate of work (as defined by a standardised rate of energy expenditure) it was more efficient to dig (and shovel) at a faster rate using more frequent rest intervals in order to maintain the faster shovelling rate, than to adopt a continuous, slower alternative regime (Table 4-5).

Freivalds 1986 concluded that for non-constrained conditions when the prime performance criterion was to attain the most efficient use of energy, high rates of shovelling (18 to 20 scoops•min^{-1}) were recommended for light- to moderate-weight blade loads (5.0 to 7.0 kg). However, low rates of shovelling (6 to 8 scoops•min^{-1}) afforded a greater work efficiency when the blade load was high (>8.0 kg). Table 4-4 provides a summary of the studies that were considered by Freivalds 1986 when establishing this conclusion.

Table 4-4: Summary of Findings for Recommended Rates of Shovelling and Blade Load when Considering Work Efficiency

Shovelling Rate (scoops·min^{-1})	Blade Load (kg)	Throw Height (m)	$^{\beta}$ *Source*
n/a	9.7	*n/a*	*Taylor 1913*
18	4.5	*n/a*	*Stevenson and Brown 1923*
5 to 8	11.0	*n/a*	*Kommerell 1929*
8	7.0 to 8.0	2.0	*Wenzig 1928, 1932*
15 to 20	8.0	*n/a*	*Spitzer 1950, Dressel et al., 1954*
15 to 20	5.0	*n/a*	*Műller and Karrasch 1956*
*5 to 6	6.8	*n/a*	*Wyndham et al., 1969*
*7	7.0 to 10.0	*n/a*	*Buskirk et al., 1972, 1975*

* *Data for working in constrained mining conditions.*

$^{\beta}$ *Data from these studies were reported in Freivalds (1986).*

Table 4-5: Gross Efficiency and Shovelling Time as a Function of Shovelling Rate and Blade Load for Work Conducted at a Standardised Rate of Energy Expenditure (13.9 KJ•min^{-1}) (Adapted from Lehmann 1953)

		Rate of Digging (Number of Shovel Scoops·min^{-1})													
		20		15		12		10		6.67		5		4	
		Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)	Efficiency %	Time (mins)
Blade Load (kg)	3	3.58	34.0	3.43	43.3	3.30	52.2	3.16	60.0						
	6	4.64	22.0	4.53	28.7	4.41	34.9	4.32	41.0	4.00	57.0				
	9	5.15	16.3	5.06	21.3	4.95	26.1	4.90	31.0	4.64	44.0	4.39	55.6		
	12	5.45	12.9	5.39	17.1	5.31	21.0	5.25	24.9	5.03	35.8	4.78	45.3	4.60	54.6
	15	5.66	10.7	5.59	14.1	5.53	17.5	5.41	20.5	5.27	30.0	5.08	38.5	4.92	46.7
	18	5.80	9.2	5.75	12.1	5.68	15.0	5.62	17.8	5.48	26.0	5.25	33.2	5.06	40.0

Studies were inconclusive with respect to the effect of the weight of the entire shovel on the total energy cost of a shovelling task. Although lifting a shovel of lesser mass (kg) would incur a lower energy cost compared to a heavier alternative (Kirsch 1939) for the exact same task (shovelling technique, posture, rate, duration, material, blade load, throw height and distance, etc.) it was not clear from the literature whether a lighter shovel would actually reduce the energy cost of shovelling[7].

However, in terms of the time to displace a set volume of material it had been reported that use of a heavier shovel (2.27 to 4.00 kg) was more efficient than a lighter alternative by virtue of the greater load-carrying capacity of the blade (Stevenson and Brown 1923). An optimum shovel weight of 1.5 to 1.8 kg was proposed at which energy economy was believed to be improved for a standard shovelling task (Műller and Karrasch 1956). However it was unclear whether sufficient control measures had been implemented in the studies that were used to support this proposal.

4.5.5 Posture and Technique

Research investigating digging technique and posture has tended to report data for work efficiency or energy expenditure as the 'criterion measure' when comparing performance on standardised digging tasks.

Table 4-6: The Effect of Blade Load, Weight of the Shovel and the Shovelling Rate on Energy Expenditure Observed for Every 100 kg of Material Shovelled (Adapted from Műller and Karrasch 1956)

Blade Load (kg)	Shovel Weight (kg)	Shovelling Rate (scoops•min^{-1}) mean (1SD)	Energy Expenditure (KJ•min^{-1}) mean (1SD)
3.0	1.3	30.0 (0.0)	20.9 (0.0)
4.0	1.5	22.5 (2.5)	20.8 (1.2)
5.0	1.8	18.0 (2.0)	19.0 (0.9)
7.0	2.0	9.0 (2.6)	26.2 (5.3)
11.0	3.5	4.5 (0.7)	31.4 (1.3)

Therefore an increased task efficiency (as reported in the open literature), attributed to a specific digging technique may actually incur a greater energy cost when compared to an alternative technique performed on a standardised task (i.e. investigators have tended not to normalise their criterion measure of efficiency for energy expenditure). When the energy cost of digging was used to assess performance as the criterion measure it was found that the energy expended during shovelling increased with the decrease in working space (i.e. constraining[8] an individual's shovelling posture incurred the greater energy cost when comparing performance for the same task and technique under conditions where posture was not constrained). Work efficiency was shown to reduce as shovelling posture was increasingly constrained (Kommerell 1929 (see Figure 4-1)).

[7] Data which quantified the energy cost of digging and shovelling using heavy or light tools had not controlled for the differences in material conditions, rates of work, differences in tool design etc. It had not been established whether a spade of very low total weight would require greater force generated by the individual, or a larger number of digging actions (and hence greater energy) in order to penetrate and loosen the material than a heavier alternative.

[8] The term 'constraining' has been used to describe an environment that has limited space available within which to work (e.g. low-seam mining) and therefore results in a cramped posture.

Figure 4-1: The Effects of Confined Space on the Posture that can be Adopted During Digging and Shovelling Tasks in the Military.

Lowering the seam height (and hence the headroom) from 1.2 to 1.0 m was reported by Kommerell 1929 to increase the energy cost of shovelling as a result of the cramped posture that subsequently resulted[9]. Morrissey et al., 1983 reduced the working height for their participants from a self-selected, upright, erect standing posture (i.e. 100%) to 60% of erect height (i.e. bent forward with 40° flexion at the waist). This was shown to increase the energy expended for their standard shovelling task by 13%.

A kneeling posture was found to require 6.5 to 10.0% less energy than an erect standing posture (Buskirk et al., 1972, 1975). However this was only true for shovelling tasks where the throw height and distance was not constant. Humphreys et al., 1962 conducted a regression analysis with their data to develop predictive equations for the energy expenditure of kneeling[10] and standing[11] when shovelling coal from ground level to a 0.23 to 0.30 m tall conveyor belt which required a throw distance of 0.91 m.

The technique that was used to perform a standard shovelling task was shown by Wenzig 1932 to influence the total energy cost (and the rate of energy expenditure). A technique that involved facing the material whilst shovelling (aligning the material in the mid-sagittal plane) and throwing the blade load

[9] These results were not normalised with respect to stature of the participants (i.e. the effect of the reduction in seam height for taller vs. shorter participants).

[10] Energy expenditure of shovelling coal onto a conveyor belt when kneeling ($Kcal \cdot min^{-1}$) = 1.34 + 0.19 (shovelling rate) Humphreys et al., 1962.

[11] Energy expenditure of shovelling coal onto a conveyor belt when standing ($Kcal \cdot min^{-1}$) = 4.91 + 0.06 (shovelling rate) Humphreys et al., 1962.

over the shoulder to a destination located behind the individual (i.e. the person digging), incurred the lowest energy cost for a standing posture (this was found to incur 18% less energy than shovelling side-ways to the material (with the material in the mediolateral plane)).

The length of the shovel's handle and shaft (together with its general design) has been shown to determine which technique and posture an individual will adopt when digging the same material (Freivalds 1986). Shovels with a long shaft (~2.5 m) may reduce the degree to which an individual may stoop when digging (Partridge 1973) (i.e. reducing the angle of flexion at the waist). Shaft/handle lengths ranging from 0.48 m (Wenzig 1928) to 0.84 m (Wenzig 1932) have been investigated and for constrained work environments (i.e. digging in a low seam height, such as in mining) a length of 0.66 m has been found to require up to 10% less energy than the longer shovels (Kommerrell 1929). However, too few data have been reported for unconstrained environments to make a general recommendation on the optimum (for energy economy) length of the shaft (shovel). Grandjean 1971 had reported that digging in a stooped posture was only 3% efficient (in terms of energy economy for a defined work load) compared to 6% efficiency in a less stooped posture. Bridger et al., 1997 suggested that their levered spade, which reduced the flexion angle at the waist (i.e. stooping posture) by as much as 40% may similarly be expected to reduce the energy cost of digging when compared to the standard spade.

Use of a 'scraping technique' to move material onto the blade of the shovel prior to throwing it to the target spoil was found to require less energy than using force to penetrate the material when shovelling material of a grain size which ranged from 7 to 15 mm diameter (Stevenson and Brown 1923). Dressel et al., 1954 reported a 15% reduction in the energy cost of digging when using this scraping technique by comparison.

4.5.6 Nature of the Material

The energy cost of shovelling was greater as the coarseness (and granularity) of the material increased for tasks that were standardised for rate and duration (Freivalds 1986). The rate of energy expenditure was shown (Table 4-7) to increase when shovelling more coarse materials (as defined by the diameter of the grain of the shovelled material). This finding was attributed to the greater force that was required to penetrate the material during the dig phase (see Figure 4-3).

Table 4-7: The Effect of the Coarseness of the Shovelled Material and Throw Height on Energy Expenditure (KJ•min^{-1}) Observed for Every 100 kg of Material Shovelled (Adapted from Dressel et al., 1954)

Throw height (m)	Material used to shovel				Energy expenditure (EE) (KJ•min^{-1}) **mean** *(1SD)*	Relative change in EE from preceding throw height (%)
	Sand	Split brick *(< 5 mm diameter)*	Gravel *(7 to 15 mm diameter)*	Gravel *(15 to 30 mm diameter)*		
0.5	18.6	22.6	23.9	27.8	**23.2** *(3.8)*	*n/a*
1.0	22.6	26.1	27.8	32.1	**27.2** *(4.0)*	17.0
1.5	26.1	29.8	30.9	34.8	**30.4** *(3.6)*	12.0
mean	**2.4**	**26.2**	**27.5**	**31.6**		
(1SD)	*3.8*	*3.6*	*3.5*	*3.5*		
	Relative change in EE (%) from preceding material type					
(%)	*n/a*	16.8	5.3	14.7		

Dressel et al., 1954 reported a 57% increase in energy expended when shovelling gravel compared with sand (however it was not clear whether a standard volume or mass was used to compare shovelling these materials). In general shovelling split brick required 17% more energy than shovelling an equal mass of sand, whilst shovelling large grain (15 to 30 mm diameter) gravel required 37% more energy than shovelling an equivalent mass of sand.

4.5.7 Subjective Assessment of Strain During Digging

Carrasco et al., 1992 reported data for:

a) Rating of Perceived Exertion ((RPE) 6 (very, very light) to 20 (very, very heavy) scale, Borg 1973);

b) Body map of perceived physical strain;

c) Postural load (using the Ovako Working Posture Analysing System); and

d) Heart rate when one very experienced male miner (the 'participant', a 34 year old with a body mass of 95 kg, and standing height of 1.96 m) conducted 80 repeated digging tasks in an Australian colliery (dry bulb temperature 17°C and relative humidity of 81%).

The participant shovelled 1000 kg of coal in 6.5 min from ground level in a working colliery, over his shoulder to the height of a conveyor belt, at a self selected (but realistic) work rate (reported to be 85% of his estimated maximum heart rate). He completed this task twice with the same shovel, but on one occasion he wore his full coal mining equipment (which included a protective helmet and equipment belt worn about the waist) and on the second occasion he was allowed to select light-weight clothing.

Results showed that in both dress conditions the subject completed the digging task standing up with a blade load that did not exceed 10 kg. However, when he wore his miners' clothing be spent 20.5 % of his total work time supporting his full body mass on one leg, he assumed a forward bent posture (flexed at the waist) for 60% of his total working time whilst a further 19.2% time was spent in a bent and twisted posture. RPE was 13 for both dress conditions and the areas of the body that were perceived to suffer the greatest physical strain (back, arms and legs) were the same for both dress conditions. However when RPE was used to assess local physical strain at these body areas, data were reported as follows:

Lightweight clothing : Back: 15; Arms: 14; Legs: 7;

Miners' clothing : Back: 14; Arms: 11; Legs: 9

Freivalds 1986b found that the shoulders, arms and lower back suffered the greatest physical strain during shovelling as reported by participants who were asked to provide an RPE rating for the areas of the body (body map (Wilson and Corlett 1995)) that they considered to have been exposed to the greatest physical stress. When shorter shovels were used by these participants their RPE subsequently increased signifying a greater perceived physical strain.

Frievalds 1986b proposed that this increased RPE which had resulted from using shorter shovels was a result of the greater flexion at the waist (i.e. participants were excessively bent-over in a stooped posture). However, when the length of the shovel was constant, RPE was higher (at the same body map areas) when heavier shovels were used (i.e. as the mass of the shovel increased).

In a later study Freivalds and Kim 1990 developed a prediction equation for RPE when conducting shovelling tasks:

$$\text{RPE (6 to 20 scale)} = 7.83 + 0.0282\ L + 2.37\ W$$

(r = 0.47)

(Where RPE = rating of perceived exertion (Borg 1973); L = blade load shovelled per minute ($kg \cdot min^{-1}$); W = shovel weight (kg))

Sen and Sahu 1996 reported RPE values of 11 to 12 when participants in a study to evaluate two types of shovel were asked to rate their perceived exertion at the shoulders, arms and back. In agreement with the findings of Frievalds 1986b, it was shown that RPE increased with the decrease in the length of the shaft and handle for the shovel. This was believed to be a consequence of the greater flexion angle at the waist that resulted when digging with a short- as opposed to a long-shovel. When the length of the shovel was maintained RPE was found to increase with an increased mass of the shovel's blade.

Degani et al., 1993 obtained RPE data on the category-ratio scale developed by Borg 1982 (0 (nothing at all) to 10 (very, very strong)) to assess the perceived physical exertion (for 10 body areas[12]) of 8 male industrial workers (the participants) every 15 minutes throughout a 95 minute shovelling task. Participants used a standard shovel to dig a trench in dry sand that was 0.60 m wide, 0.90 m deep and 4.50 m long. The task was self paced and conducted in a posture that was preferred by the participant. Mean RPE when combining data reported for each body area was 2.7 (weak to moderate), whilst the greatest perceived exertion (mean data) was reported for the lower back (RPE 3.5), and the upper back (RPE 2.2). RPE at the lower back generally increased by 0.5 for every 15-minutes of continuous digging within the total 95-minute time for the task.

4.5.8 Clothing (Dress Order)

During operations military personnel are expected to be equipped and ready to conduct their military duties at all times. Such a requirement has resulted in service personnel conducting their digging and shovelling tasks whilst wearing their combat clothing and full fighting order (including a weapon or fire-arm and helmet) (Gribble 1971). Operational equipment and clothing has been shown to increase the burden on dismounted service personnel by as much as 25.0 kg (Nevola et al., 2003a). The addition of such a large mass on the body (and the restriction that such equipment imposes on the range of movement that could be achieved) whilst conducting digging and shovelling tasks, may partly explain the distinct difference in the data when comparing civilian and military occupations.

The development of job-based task simulations with which to assess the physical fitness of fire-fighters in Canada (Gledhill and Jamnik 1992) required individuals to wear the standard protective clothing (which added a further 48 lb or 21.8 kg to the total mass of the individual) that was a requirement of this occupation's operational role.

4.5.9 Lift Angle

When a series of lift angles[13] (0°, 16°, 32° and 48°) were used in a controlled digging task[14] the energy efficiency (calculated from expired gases which were analysed using an MM1 Metabolic Monitor (Freivalds 1986b)) was greater (i.e. preferable, $p<0.1$) for 16° and 32° when compared with the other lift angles. RPE was significantly lower when digging with shovels that had these more energetically favourable lift angles (i.e. 16° and 32°) in preference to the shovels with 0° or 48° lift angle. The increased flexion at the waist that was required to use a shovel with a 0° lift angle was proposed as an explanation of the comparatively high energy cost of the digging task. However, although use of the shovel with a 48° lift angle effectively reduced the flexion angle at the waist (compared with the lesser lift angles) Freivalds 1986b noticed that more sand was actually lost from the blade and hence the higher energy cost was incurred as a consequence of the increased number of scoops required to dig an equivalent quantity of

[12] Corlett and Bishop 1976 body map was used and the 10 body areas were: hands, forearms, upper arms, shoulders, left and right aspects of the trapezius muscles, upper back, lower back, left-leg hamstrings and right-leg hamstring muscles.

[13] For an illustrated definition of the *lift angle* see *Figure 4-5*.

[14] Digging foundry sand which had been moistened to 2.5 to 4.0% water content from ground (0.0 m) to 0.7 m height and throwing it a distance of 1.4 m at a shovelling rate of 18 scoops·min^{-1} (set by a metronome) lasting 2 hours at a work: rest regime of 5 min work : 5 min rest.

sand. Participants in a digging study conducted by Montazer et al., 1989 provided their lowest RPE values when they used shovels with a lift angle in the range 0° to 30°.

4.5.10 Biomechanics: Effect of Posture and Technique on Task Performance

Stickland 1995 provided a definition of the various phases observed during a digging and shovelling task in the British Army. This definition has been adapted into an illustrated format in Figure 4-3 and Figure 4-4 respectively and in the absence of a comprehensive kinematic analysis within the scientific literature it has been adopted as the 'standard' procedure for the purpose of this document.

Measurement of the vertical displacement of the centre of mass of the body during a standard digging task have been made using a LIDOKAS (Loredan Biomedical Ltd, USA) posture measurement system (Bridger et al., 1997). The results described a vertical displacement of 16.5 cm for a conventional spade (Figure 4-9) and 9.4 cm for a novel variant 'levered' spade which had 2 handles.

Lower-back compressive forces (F_{comp} [15]) during a standard digging task (Freivalds 1986b) tended to increase linearly with the decrease in lift angle of the spade of the shovel (i.e. F_{comp} was low at a lift angle of 48° and high at 0°).

Freivalds 1986b proposed an equation to estimate F_{comp} for a specific digging protocol (footnote #15, Section 4.5.9 provides a description of the task) based on the lift angle of the shovel:

$$F_{comp}\ (N) = 4102 - 7.74 \times (\text{lift angle } (°))$$

The highest values for F_{comp} that Freivalds 1986b obtained during their shovelling tasks was 4000 N, and it occurred with a shovel that had a lift angle of 0° and a shovel load of 9.0 kg (which included the mass of the shovel's blade). Axial compression tests on the vertebrae of cadavers have shown stress fractures to occur at F_{comp} of 6750 N for adults under the age of 40 years, and at 3000 N for adults older than 60 years. Sonoda 1962 reported a 17% lower tolerance to F_{comp} with regard to the calculated risk of vertebral stress fracture in women when compared to men. NIOSH[16] 1981 set an upper action limit of 3400 N when considering F_{comp} and the risk of injury to the spine. However, this action limit did not consider the important work-related risk factors such as task repetition, the duration of the task, or the biological age and body mass of employees who were required conducted the work.

Jorgensen et al., 1999 designed a study to investigate the psychophysical criteria that determined the maximum acceptable weight of lift (MAWL) when their fifteen male participants conducted a series of two-handed box lifts from the knee- to waist-height at a rate of 4.3 lifts•min^{-1} adjusting the weight of the box to match their perceived MAWL. A series of physiological and biomechanical parameters were monitored which had been previously identified as risk factors for lower back disorders (LBD). Using a 3D lumbar motion monitor (Marras et al., 1993), bipolar surface EMG (for 10 muscle groups located at the trunk), and a method developed by Fathallah et al., 1997, they were able to calculate the internal moments and forces at the 5th lumbar (L5) and 1st sacral (S1) vertebrae (and the L5-S1 intervertebral disc). Results demonstrated that self selected MAWL was a poor indicator of LBD risk. When a weight that was similar to a heavy shovelling task (i.e. 9.1 kg) was lifted repetitively for several minutes, the average maximum spinal forces of: 561.5 N (lateral shear force); 1091.1 N (anterior/posterior (A/P) shear force); 5174.4 N (compressive force) at the L5-S1 intervertebral disc were evident. Although these forces were considered by the participants to be acceptable, according to NIOSH 1981 microfractures of the vertebral endplates would be expected in 50% of the working population in the USA at compressions of

[15] F_{comp} were estimated (using the University of Michigan 3-D biomechanical strength prediction model (Chaffin and Baker 1970)) from postural angles that were evident from still photographs of actions that had been conducted during a standard digging task (Frievalds 1986b).

[16] National Institute of Occupational Safety and Health (NIOSH).

only 6400 N. Furthermore McGill 1996 estimated that the shear force tolerance of L5-S1 was only 1000 N, which was exceeded in Jorgensen et al., 1999's calculations for A/P shear force when lifting only 9.1 kg in their study. The compressive forces for lifting the same weight from ground level, whilst standing flexed at the trunk (a typical posture evident in digging tasks), has been shown to exceed MAWL for LBD (Jorgensen et al., 1999). Furthermore, this study concluded that factors which appeared to be associated with the voluntary regulation of repetitive lift weight were heart rate and sagittal moment.

Degani et al., 1993 placed bipolar surface electrodes over the lumbar paraspinal muscles of seven male participants in their study. The full-wave rectified integral (FWRI) EMG[17] value for 3 shovelling conditions were assessed for each participant. Conditions involved holding one of two shovel loads (4.5 kg and 6.8 kg) for a 6 s period at three different heights above ground level (0.025 m, 0.28 m, and 0.56 m). Comparison of the FWRI for each condition and treatment identified that shovel load and height were statistically significant ($p<0.05$) influences on the electrical activity of these muscle groups. FWRI remained at approximately 600 µV for each lift height when raising the 4.5 kg shovel load, however for the heavier (6.8 kg) load FWRI increased from 700 µV (0.025 m height) to 950 µV (0.56 m height).

Methods involving the analysis of digitised video recordings (kinematic analysis[18]) and basic measurements of equipment weight were used to assess back loads during trench digging and shovelling soil in a study that was conducted for a Dutch municipal drinking-water distribution department (Van der Grinten 1987). Back load was found to be greatest at the beginning of the lifting action (the 'extract (lift)' phase 'f', Figure 4-3) observed prior to the throw phase, when the trunk was at its most flexed posture. Use of a simple model enabled compression and torsion moments at the L5-S1 to be estimated. Van der Grinten 1987 calculated moments about L5-S1 of 200 Nm during digging, and 185 Nm for shovelling, with an average shovel load of 7.5 kg and 5.0 kg respectively. Data to describe twisting and forward flexion moments at L5-S1 were also reported (see Figure 4-2).

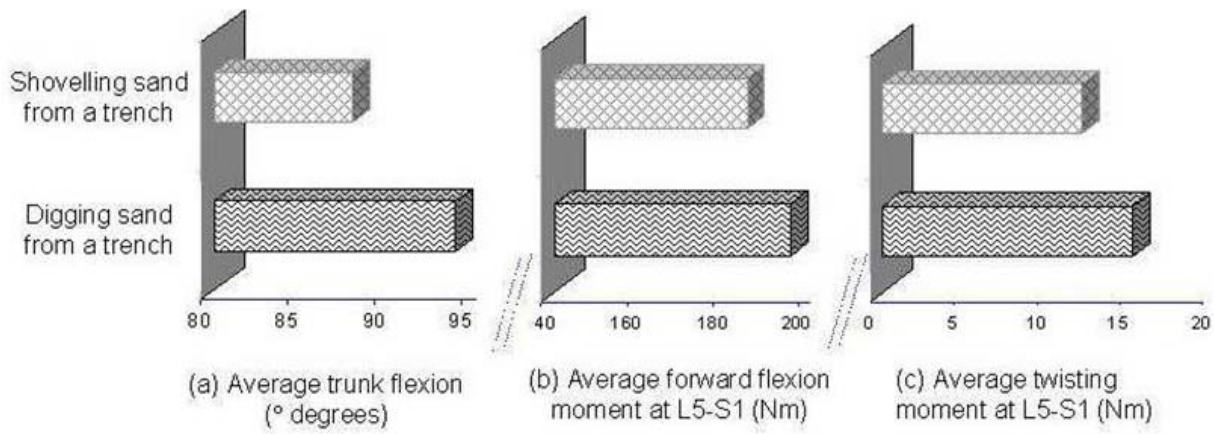


Figure 4-2: Data Reported by Van der Grinten 1987 for Digging and Shovelling Sand from Trenches (at the beginning of the lifting action): (a) Average forward flexion of the trunk; (b) average moment in the lower back at L5-S1; and (c) average twisting moment at L5-S1.

[17] EMG: Electromyography.

[18] Analysis of posture was conducted for still imagery and goniometry when measuring angles between markers that had been placed adjacent to joint centres of motion.

Figure 4-3: Standardised Digging with a Shovel in Accordance with British Military Procedures (Stickland 1995).

(i) Shovelling technique observed at the *'recover and set'* phases.

(ii) Alternative kneeling technique observed to dig material.

Figure 4-4: A 'Recover and Set' Phase Variant Observed During Shovelling Tasks, and an Alternative Kneeling Method that has Been Used by Military Personnel.

Hansson and Öberg 1996 estimated the time course and size of the dynamic compression and shear forces at L5-S1 and within the musculature that supported the L4-L5 lower back[19] during digging and shovelling with a standard shovel (weight 6.5 kg, shaft length 1.0 m and a lift angle of 45°). They found that all variables that were analysed had their 'peak' values during the initial extract (lift) phase when moving the shovel. The size of the dynamic forces in the lower back were decreased when the shovel began to move in the horizontal direction. Shear forces at the spine reached a maximum (approximately 425 N) at the

[19] A 3-D biomechanical model developed at the University of Michigan 1993 was used to calculate these forces. Data obtained from an infrared camera system (50 Hz, Mac-Reflex, Qualisys 1993) which tracked the movement of retroreflective markers that had been placed at specific anatomical landmarks on participants provided the data that were required to generate the force estimates.

start of the lift when the trunk was at its most flexed posture. Maximum compression force at L5-S1 (approximately 2700 N) was reached[20] when the trunk was flexed to 90°. Peak forces calculated at the right Erector spinae and Latissimus dorsi during shovelling were approximately 1000 N and 220 N respectively. In both muscle groups the peak forces occurred when the spine was at its most compressed. A simple relationship between trunk flexion angle and spinal load was proposed by Hansson and Öberg 1996. They found that maximum compression forces appeared when the trunk was in the horizontal position (i.e. 90° flexion) but the shear forces continued to increase when the trunk exceeded 90° flexion. Hence they suggested that use of longer shovels would effectively incur lower compression and shear forces when compared with shovelling from ground level using a shovel which had a very short shaft (common in military entrenching tools). However, longer shovels incurred a greater lateral moment loading the trunk as a result of the need to place a hand much further down the shaft to lift the shovel. This moment was considered to be counteracted by the increased muscle action of the Erector spinae.

Forces at the intervertebral disc between the 3rd (L3) and 4th lumbar (L4) vertebrae were calculated by Öberg 1993 for an 80.0 kg participant during a shovelling task with a conventional 1.5 kg shovel (blade load of 5.0 kg, dry sand) to be:

a) Tensile force: 3754 N;

b) Compressive force: 4087 N; and

c) Shear force: 310 N.

The anthropometry of the individual user (the 'participant') was an important factor when considering the physical strain during a standard shovelling task (Hansson and Öberg 1996). When using a 6.5 kg shovel (length 1.0 m) participants who were small (height 1.69 m, body mass 63.0 kg) demonstrated less flexion at the trunk when compared with large participants (height 1.87 m, body mass 92.0 kg), and they had a smaller body mass with which to load the spine and consequently they were reported to experience smaller compressive forces at L5-S1. They concluded that handling heavy material with a shovel resulted in disc compression and shear forces that may be harmful to the operator. The often repetitive nature of shovelling was considered to compound the risk. A shovel with a longer shaft than normal decreased the operator's trunk flexion when beginning to lift the shovel from the ground. The maximum shear forces at the spine were also decreased. However, the lateral moment loading the trunk was increased and the maximum force at the right Erector spinae muscle was also increased. Use of a shovel with a lift angle greater than 10° appeared to decrease the maximum spine compression and shear forces when lifting the shovel from the ground. When lifting the shovel, the load on the spine and on the back muscles was much greater for tall and heavy operators when compared with short and lightweight operators.

4.5.11 Shovel Design

(Additional information may be obtained from Section 4.5.10 concerning the influence of equipment design features on the biomechanics of digging and shovelling).

Matching the physical properties of the shovel to the type of material for which it is to be used, is essential, e.g. a heavy-weight, high-density, stiff metal (high Young's Modulus), blade would arguably be more effective at shovelling a material composed of heavy clay, or broken rock in preference to a lighter-weight, low density, malleable equivalent of equal dimensions. However, when considering compliance with the human user, managing local muscle fatigue as a result of extended periods of bending is one of the principal concerns facing designers of manual digging equipment. Local muscle fatigue in shovelling is affected by the type of shovel, the height of the task, how high the shovel must be raised, and the weight of the material on it (cited in Degani et al., 1993). Spades have been intended to be used to cut turf and to lift soil (referred to as the 'material') during the task of digging a hole, ditch or trench.

[20] This occurred within the first 0.2 to 0.5 seconds of applying force on the shovel.

The shaft of the spade has typically been straight and has traditionally been made from wood. The length of the entire spade has been adjusted to meet the 50th percentile standing elbow height, or waist height of the male user population (Drillis 1963).

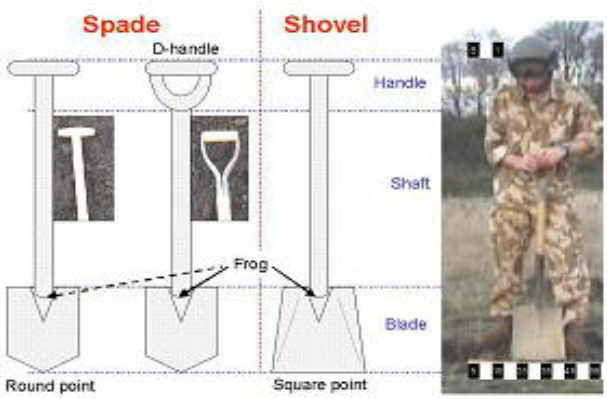
Features of the equipment (please refer to Figure 4-5, and Figure 4-7 to Figure 4-9) have a direct impact on task performance, sustainability and the risk to the user of acute and chronic injury. A number of discrete features of shovel design have been investigated in the open literature with the intention to:

a) Improve work productivity (shovelling efficiency);

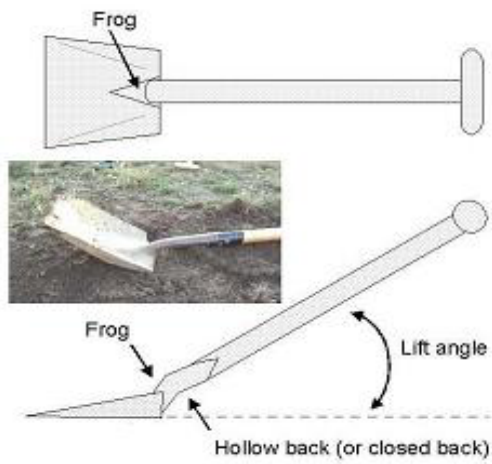
b) Improve energy economy (and thereby sustainability of work throughout the required shift and at the expected work rate); and

c) Reduce the risk of task-related injury.

Research tended to focus upon only one of these 'intentions' for influencing the design of the shovel. Hence there is no single design that achieves all three intended targets. Furthermore, manual digging equipment is rarely provided to fit the individual user, hence the in-service design may favour short employees and disadvantage taller individuals.



(i) A standard spade and shovel.



(ii) A standard shovel.

(iii) Classification of terms used to describe digging tasks.

Figure 4-5: Standard Equipment, Terms and Dimensions Commonly Used to Describe Digging and Shovelling Tasks.

Research to investigate individual design features of digging and shovelling equipment can be readily found in the ergonomics-based journals. The characteristics of the shaft and handle were often investigated, and similar results were reported. McGorry et al., 2003 investigated the shaft configuration on shovelling performance in the snow and they found that increasing the lift angle of the shovel significantly reduced the trunk flexion required to effectively complete an 8-minute digging task.

Pheasant and O'Neil 1975 found that the maximum shear force at the handle of the shovel during the cut phase of shovelling (see Figure 4-4 part (i)) was greatest when the diameter of the handle was 30 to 50 mm. EMG[21] analysis of the flexor and extensor muscles at the elbow found that during the performance of repetitive manual tasks a stronger grip could be achieved when the handle diameter was 38 mm (Ayoub and Lo Presti 1971). Forces evident at the handle of a 'standard' shovel during a digging task were estimated using piezoelectric strain transducers (Lehmann 1953). Peak force in compression occurred at the point then the blade penetrated the target material, whilst tensile forces reached a peak during the recovery swing of the shovel shortly following the throw phase.

4.5.12 External Work and Energy Expenditure of Digging Tasks

Following a meta-analysis of the available data, two equations were proposed by Freivalds 1986 to estimate the external work (W) conducted during shovelling and the expected rate of energy expenditure ($\dot{E}$):

(eq1): W (kg•m) $= 0.514 + 0.38\ L + (0.448\ L \times D) + (0.646\ L \times H)$

$r^2 = 0.984$

(eq2): $\dot{E}$ (kcal•scoop^{-1}) $= 0.1795 + (0.0436\ H \times L) + (0.0169\ D \times L) - (0.036\ H2)$

$r^2 = 0.942$

(where: W = external work; L = Load (kg); H = throw height (m); and D = throw distance (m))

Moss (1923, 1924a, 1924b) first measured the energy expenditure (using Douglas bags) of shovelling for coal miners who were loading slack. Although the shovelling rate and blade loads were not reported, the rate of oxygen utilisation at the self selected work rate were found to range from 1.59 L•min^{-1} (Moss 1934) to 1.95 L•min^{-1}. During a 2-year study by the Max Planck Institute for Work Physiology the average energy expenditure for miners shovelling coal was found to be 14.3 KJ•min^{-1} and 13.1 KJ•min^{-1} for construction workers shovelling gravel (Lehmann 1950).

Passmore and Durnin 1955 used expired gas analysis to assess the energy expenditure of shovelling for a population of coal miners. Shovelling yielded a rate of expenditure in the range 29.7 to 32.2 KJ•min^{-1}. Åstrand and Rodahl 1986 summarised the results of studies which had assessed the energy expended by coal miners whilst shovelling (working with a pick and shovel) and they reported a typical range from 25.0 to 29.0 KJ•min^{-1}. Research which had been cited to have investigated the oxygen utilisation during shovelling for a number of different postures ranged from 1.0 to 2.0 L•min^{-1}. Åstrand and Rodahl 1986 classified the corresponding 'work intensity' evident during digging and shovelling tasks as heavy (1.0 to 1.5 L•min^{-1}) to very heavy work (1.5 to 2.0 L•min^{-1}). This was similar to data reported by Chakraborty et al., 1974 for Indian coal miners (28.8 KJ•min^{-1}) but much lower than the 39.3 KJ•min^{-1} reported for an equivalent shovelling task in a population of Italian coal miners (Granati and Busca 1941) and the 38.9 KJ•min^{-1} reported by Ayoub et al., 1981 for a similar population. However, Ayoub et al., 1981 found that when their participants were allowed to work a self selected shovelling rate, they maintained these

[21] EMG: Electromyography studies the size and pattern of muscle recruitment (specifically measuring the electrical activity of the observed muscle group).

high energy expenditures for only 3.8 min with a shovelling rate of 25 scoops•min^{-1} which suddenly dropped to a more sustainable 16 scoops•min^{-1} for continuous shovelling.

Pradhan et al., 1987 investigated 3 methods of using 2 variants of the common agricultural spade (spades A and B[22]) within a sample of seven male agricultural (mean (1SD) age 27.4 (5.9) years) workers in India. The 3 methods involved:

i) Digging soil from a standing posture with a 40 degree flexion at the waist, without raising the spade above shoulder height;

ii) Standing upright and using the spade as a pick axe by striking the soil with an overhead swing, and not shovelling the soil at all; and

iii) Shovelling loose soil from a standing posture (flexed at the waist) and throwing the material a distance of 1.5 m.

The results of expired gas analyses identified work rates that afforded the most efficient use of oxygen for each of the three methods and spade variant. Work rates of 38 scoops•min^{-1}, 22 and 17 scoops·min^{-1} were found to be physiologically most efficient for a sustained digging protocol when conducting methods i, ii and iii respectively. Method iii incurred the highest oxygen cost of the 3 methods despite the lower work rate, with method ii being the next most aerobically demanding. Regression analysis to predict VO_2 for the 2 spade variants produced the following equations:

Spade A: VO_2 (L·min^{-1}) = 0.03 x Digging rate (scoops·min^{-1}) +0.83

$$r = 0.66$$

Spade B: VO_2 (L·min^{-1}) = 0.02 x Digging rate (scoops·min^{-1}) + 1.20

$$r = 0.62$$

Method iii was conducted at a high relative work intensity (up to 89% VO_2max) and required a mean (1SD) rate of oxygen utilisation of 37.3 (4.9) ml•min^{-1}•kg^{-1} for a work rate of 31 to 34 scoops·min^{-1} (the depth with which the spade cut the soil was 12.7 and 13.3 cm respectively for each work rate). In all methods of digging Pradhan et al., 1987 found that the force exertion per scoop was less as the work rate increased (irrespective of the spade variant).

Bridger et al., 1997 reported a mean (1SD) rate of energy expenditure of 43.9 (7.4) KJ•min^{-1} when eleven male participants shovelled 1815 kg of sand at a controlled work rate of 25 scoops•min^{-1} (conducted to the beat of a metronome[23]) using a shovel which weighed 2.1 kg and had a shaft length of 0.60 m. The task was completed in 11.42 (1.58) min (mean (1SD)) and required a steady-state rate of oxygen utilisation of 27.2 (4.8) ml•min^{-1}•kg^{-1}.

Brouha 1960 reported an energy expenditure of 25.1 KJ•min^{-1} for a standard digging task. One study from the USA (TNC Fire 2000) estimated the mean aerobic demand for several standard tasks that were commonly conducted during wild-land fire-fighting. A VO_2 of 22.9 ml•min^{-1}•kg^{-1} was reported for a typical shovelling task. This estimate was based upon the use of the participants' estimated VO_2max

[22] Spade **A**: blade weight 1.3 kg, length of blade 21.4 cm, blade thickness 2.0 mm, length of shaft 0.68 m and total mass of the spade 1.75 kg: Spade **B**: blade weight 1.4 kg, length of blade 22.5 cm, blade thickness 2.5 mm, length of shaft 0.74 m and total mass of the spade 2.05 kg.

[23] The mean blade load was 7.0 (0.7) kg for each scoop.

(indirect assessment of maximum VO_2 to volitional exhaustion) and the relative proportion of their maximum heart rate at which the task was conducted[24].

Ainsworth et al., 1993 have quantified the energy cost of several common digging tasks and reported a predicted MET[25] value for each:

- 4.0 MET: Digging worms with a shovel;
- 5.0 MET: Digging a sand box or domestic digging (i.e. gardening);
- 6.0 MET: Light shovelling (less than 4.5 $kg \bullet min^{-1}$);
- 7.0 MET: Moderate shovelling (more than 4.5 to 7.0 $kg \bullet min^{-1}$);
- 8.5 MET: Shovelling and digging ditches;
- 9.0 MET: Heavy shovelling (more than 7.3 $kg \bullet min^{-1}$).

When a 1.33-kg shovel (handle length: 1.3 m, blade size: 0.0891 m^2, blade to weight ratio: 0.067 $m^2 \bullet kg^{-1}$) was used to conduct a 1-hour digging task (work rest routine of 5 minutes of digging following by a 5 minute rest and so on) using foundry casting sand (moistened to 2.5% saturation) that originated in a pile at ground level and was shovelled into a barrel of 0.7-m height at a horizontal distance of 1.4 m, the energy expenditure from expired gas analysis of 5 male participants (mean (1SD) age 23.0 (3.6) years; body mass 77.0 (12.2) kg; and height 1.8 (0.1) m) was calculated as 21.8 (7.4) $KJ \bullet min^{-1}$ (Freivalds and Kim 1990). This study used expired gas analysis to assess the energy expended by their participants for five variants of shovel[26], and using an ANCOVA design they reported several equations to best predict the energy expenditure of shovelling. The equation that they recommended for the 1.33-kg shovel was:

$$E = -103 + 0.0147\ L + 2.64\ Ws - 0.0159\ W2s - 0.244$$

(r = 0.907)

(Where E = energy expended (kcal); L = blade load shovelled per minute ($kg \bullet min^{-1}$); and Ws = subject body mass (kg))

When energy expenditure was normalised to the participants' body mass and the blade load, stepwise regression analysis resulted in the following equation (Freivalds and Kim 1990):

$$E = 10.2 - 0.0057 + 0.0323\ Ws - 5.74\ H - 24.5\ B/W + 177\ B/W2$$

(r = 0.906)

(Where E = energy expended (kcal); H = subject height (m); Ws = subject body mass (kg); B/W = ratio of blade size to shovel weight)

As the size of the blade increases beyond[27] that which affords the optimum 21.6 $KJ \bullet min^{-1}$ rate of energy expenditure (for a sustainable shovelling rate in an 8-hour work shift (Freivalds and Kim 1990)) it has been shown that the total load increased concomitantly with the increased weight of the shovel. Consequently the energy that was expended increased beyond acceptable levels (Freivalds and Kim 1990) and participants experienced an earlier onset of symptoms of physical fatigue. Coping strategies in the

[24] Based upon an assumed linear relationship between submaximal heart rate and VO_2 (and relative proportion of heart rate maximum to relative VO_2max).

[25] MET: The metabolic equivalent (assumed to be 3.5 $ml \cdot min^{-1} \cdot kg^{-1}$).

[26] The mass of the shovel variants that were used ranged from 0.68 to 2.25 kg, with handle length from 1.2 to 1.3 m, blade size from 0.0586 top 0.1184 m^2 and blade to weight ratio from 0.026 to 0.086 $m^2 \cdot kg^{-1}$.

[27] The optimum blade to weight ratio was reported by Freivalds and Kim 1990 to be 0.0676 $m^2 \cdot kg^{-1}$.

work place were seen to involve participants compensating for the additional weight of the heavier shovel by reducing the blade load (only shovelling half scoops) when using the larger bladed shovels. In addition to the influence of the weight of the shovel and the blade load, Freivalds and Kim 1990 reported that the weight and height of the participant (i.e. the individual who was digging) were also important predictors for the total energy cost of shovelling.

4.6 COMMON MILITARY TASKS (CMT)

Digging and shovelling tasks have been cited within military training, survival and field-craft manuals since records commenced. Common tasks that require military personnel within NATO to manually displace material using non-powered, equipment have been summarised in Table 4-8.

Table 4-8: Digging Tasks that are Common to the Military Role

Military Task Name	Task Specification *(in unfrozen terrain)*	Occupational Role	Equipment	Source Reference
Database of 18 digging tasks, representing 18 MOS'	1.0x1.0x183.0 ft trenches to emplace piping – shovelling a mean (1SD) load of 18.2 (6.6) lbs from a mean (1SD) volume of 48.9 (45.5) ft^3	US Army (laundry and shower specialists MOS 57E)	n/a	Sharp et al., 1998
Standard 4-man trench	12 x 2 x 4.5 ft (*light sand:* 88 to 65 min: *clay:* 257 to 299 min) *Work : rest cycle of 52 min digging and 8 min rest for each hour*	1st Royal Norfolk regiment, British Infantry	Pick and entrenching tool (UK)	Gould 1957
Digging pilot holes to lay explosives for excavation	Digging a (30 to 48) x 1.5-inch hole within which to deploy explosives	Royal Engineers (British Army)	Hand-held auger	Briosi 1980, Stickland 1995
2-man battle trench	1.5 m (H) x 0.75 m (W) x 3.45 m (L) With elbow rests of 0.45 m (W) x 0.3 m (H) Fill 12 to 45 sandbags for protective cover and place (and compact) 0.45 m earth above the shelter *Digging rate * per man: 0.3 $m^3 \cdot hour^{-1}$ (0.15 $m^3 \cdot hour^{-1}$ for chalk or rock) or 20 sand-bags$\cdot hour^{-1}$ per man*	Royal Engineers (British Army)	Shovel, pick axe, sand-bags, and trench materials	Briosi 1980, Military Engineering 1993 (Figure 4-14)
4-man battle trench	1.5 m (H) x 0.75 m (W) x 7.75 m (L) With elbow rests of 0.45 m (W) x 0.3 m (H) Dig five anchor wire channels 0.3 m (H) x 0.3 m (L) Fill 36 to 110 sandbags for protective cover and place (and compact) 0.45 m earth above the shelter	Royal Engineers (British Army)	Shovel, pick axe, sand-bags, and trench materials	1993 Military Engineering 1996 (Figure 4-15)

Military Task Name	Task Specification (in unfrozen terrain)	Occupational Role	Equipment	Source Reference
	*Digging rate * per man: 0.3 $m^3 \cdot hour^{-1}$ (0.15 $m^3 \cdot hour^{-1}$ for chalk or rock) or 20 sand-bags•$hour^{-1}$ per man. Expected 4-hours to complete by hand whilst revetting and camouflage will incur a further 4.5 hours.*			
Fox hole	1.80 (L) x 0.60 (W) x 0.45 (H) m crushed gravel	US Army and Canadian Infantry	Entrenching tool	Deakin et al., 2000
Shell scrape	2.0 (L) x 1.0 (W) x 0.4 (H) m sand	Armed Forces (dismounted land) (UK)	Entrenching tool	Nevola et al., 2003a (Figure 4-6a)
Shell scrape	1.9 (L) x 0.6 (W) x 0.5 (H) m sandy soft clay	Infantry (Canadian Army)	Entrenching tool	Deakin et al., 2000
Sand-bag sangar	2.5 (L) x 1.0 (W) x 1.2 (H) m sand	Armed Forces (dismounted land) (UK)	Pick axe shovel, entrenching tool	Nevola et al., 2003b
Sand-bagging	20 sand-bags filled within 60 minutes	Armed Forces (dismounted land) (UK)	Entrenching tool	Nevola et al., 2003b (Figure 4-6b)
Augering	1.3 m (H) x 0.24 m (W)	Royal Engineers and Specialist Infantry trades (UK)	Independent powered auger weighing 27 kg (Atlas Copco Pionjar, Sweden)	Stickland 1995
Rapid protection trench	0.6 m (H) dig with 0.6 m (H) wall of sandbags to afford a combined H of 1.2 m protection.	Armed Forces (dismounted land) (UK)	Pick axe and entrenching tool	Stickland 1995
Weapon emplacement, vehicle protection, and anti-tank ditches	Various	Various	Manual and powered digging tools, and trench support materials	Military Engineering 1993
Slit trench, latrine, de-turfing, fire trench		Armed Forces (land) (UK)	n/a	n/a

Where the dimension have been reported as: H (height), W (width) and L (length);

** Time to dig the allocated volume of material per man is increased by a factor of: (a) 1.4 when wearing NBC protective clothing (category 2 dress) in warm weather; (b) 1.3 when working at night; and (c) 1.8 for tired or inexperienced troops.*

4.6.1 CMT Analysis

Stickland 1995 described a standard operating procedure for a common military digging task using a conventional (in-service) shovel. This technique has been illustrated in Figure 4-3.

(a) (b)

(c)

Figure 4-6: Common Military Tasks (a) Digging a Shell Scrape, (b) Filling Sandbags (Sandbagging), and (c) Digging Trenches.

Army code no.71271 (Pam 2) 1993 provided guidance to Royal Engineers (soldiers) in the British Army concerning the occasions when manual digging was expected, the target rates of work and some advice on best operational practice in-theatre. The pamphlet recommended that soldiers dug in pairs, and faced the same direction when digging. Discarded material (the spoil) was required to be placed above the trench and on the side that was closest to the enemy position. Filling sandbags was expected to be completed at a rate of 20 bags•hour^{-1}·man^{-1} and when 'combat digging' soldiers were advised to aim to dig 40 m•hour^{-1} (or 40 m•hour^{-1} if the trench construction was located on the side of a hill).

The digging and shovelling required to construct a 4-man trench was expected to be completed in a target time of 4-hours. During user trials to assess the effectiveness of several variants of the military entrenching tool (hand) (ETH), Walker 1979 found that the mean (1SD) time for 4 soldiers to dig a 4-man trench was 5.1 (0.2) hours (data were compared for trench digging in the chalk ground of Salisbury Plain (UK) and the soft clay soil in Germany).

4.7 DIGGING EQUIPMENT (MANUAL LABOUR)

Shovels have been designed to lift and move loose material. The shovel consists of a square, flat blade with raised edges, connected to a shaft at the end of which there is a handle. Drillis 1963 stated that the length of the entire shovel had been based upon the standing height of the user's xiphoid process (50th percentile stature for the male user population). When a handle was present on the shovel it had often been shaped to a 'T' or 'D' grip (see Figure 4-5). The angle of the shaft to the horizontal was called the 'lift' and provided the shovel with added leverage. In a survey of digging tools that were most often used by Swedish workers, the 'standard' shovel was found to have a straight shaft of 1.0 m in length, a 35° lift angle, with a total weight of 6.5 kg (un-laden) (Hansson and Öberg 1996).

The most common non-powered, manual equipment that has been used by personnel within NATO during military operations have been described in Figure 4-7, Figure 4-8, and Figure 4-9.

	Pickaxe (Lightweight)	**Earth Auger**	**Folding Spade**	**Pickaxe** (General Service)	**Pickaxe** (General Service)
Mass (kg)	2.00	6.00	1.16	3.23	2.70
Length (m)	0.66	1.06	0.58	0.91	0.95
Max. Width (m)	0.40	0.11	0.24	0.47	0.50
	UK	*UK*	*NATO*	*UK*	*Austria*

Figure 4-7: Equipment Used to Break or Loosen Ground Material within the Armed Forces of NATO.

	Entrenching Tool Hand (ETH) (Lightweight)	**Entrenching Tool**	**Entrenching Tool**	**S-Pick** (Combined Spade and Pick)	**Entrenching Tool Hand**
Mass (kg)	1.18	1.70	1.13	~0.25	1.25
Length (m)	0.59	0.60	0.60	0.65	0.65
Max. Width (m)	0.15 *(blade)*	0.17	0.16	0.40	0.15 *(blade)*
	UK	*USA*	*Germany*	*UK*	*Austria*

Figure 4-8: Equipment Used to Cut and Displace Ground Material within the Armed Forces of NATO (Part 1).

	Shovel *(General Service)*	**S-Pick *(Spade Configuration)***	**S-Pick *(Pick Configuration)***	**Spade**	**Shovel**	**Spade**
Mass (kg)	2.50	~0.25	~0.25	2.00	1.80	1.90
Length (m)	0.92	0.95	0.65	0.85	1.53	1.21
Max. Width (m)	*0.25 (Blade)*	0.20	0.40	0.18	0.28	0.25
	UK	*UK*	*UK*	*UK*	*Austria*	*Austria*

Figure 4-9: Equipment Used to Cut and Displace Ground Material within the Armed Forces of NATO (Part 2).

Dismounted land forces serving in the UK military have 5 types of equipment available to conduct manual digging tasks:

a) Pick axe (General Service) (Figure 4-7);

b) Shovel (General Service) (Figure 4-9);

c) Pick axe (lightweight) (Figure 4-7);

d) Spade (Figure 4-9); and

e) Entrenching tool hand (ETH) (Figure 4-8).

4.7.1 Tools Used to Loosen the Ground Surface

Tools commonly used by military personnel within NATO to break and loosen material have been described in Figure 4-7. Although it is beyond the scope of this report to discuss explosive excavation techniques, the setting of charges that are used in such methods have an initial requirement for drilling or digging holes within which the explosives may be placed. These holes are often dug by hand using one of two methods:

i) Drill kit impact manual (weighing 28 kg); and

ii) Kit Explosive Digging Aid (KEDA L12A1, weighing 1.62 kg).

Augers were considered by Briosi 1980 to offer advantages in terms of time and energy over the use of shovels and pick axes when digging in cohesive materials such as silts and clays (which are likely to be the most difficult (unfrozen) soils in which to dig holes). Excavation (of small holes or trenches) in sand or gravel were considered to be more rapidly completed using a shovel.

4.7.2 Tools Used to Cut and Displace Material

The tools that were commonly used (until 2004) by military personnel within the 26 Nations of NATO to cut and displace material have been described in Figure 4-8 and Figure 4-9.

Reference to the S-Pick concerns the prototype digging tool that had been developed within the UK for British troops to use on operations and which could be configured into a lightweight pick axe or a spade.

4.8 PHYSICAL DEMANDS OF CMTs: PHYSIOLOGICAL REQUIREMENTS

According to the calculations of Stickland 1995 a battalion in the British Army required the equivalent of 113, four-man trenches to be dug in accordance with military procedures. Each trench occupied a total of 6.912 m^3 which was often dug from a clay-based material (the estimated density of clay was reported to be 1.768 $kg \bullet m^{-3}$). Stickland 1995 calculated that during Exercise Bold Grouse, the battalion in which he served had dug 12.2 tonnes of material for each of the 113 trenches that the commanding officer had ordered to be excavated by hand (and completed within a 24-hour period). In total the battalion dug 1380 tonnes of material by hand, 183 tonnes of which was also used to fill 14,342 sand-bags. A simple estimate of the work required by each soldier was reported by Stickland 1995 as follows:

Work = (Total mass of material excavated x g[*] x mean height to which the dug material was lifted) x (mass of the shovel x the number of digging actions conducted x the mean height of each excavation)

Following a number of assumptions Stickland 1995 estimated that each soldier would conduct approximately 124,969 digging actions (see Figure 4-3), and incur an estimated energy cost of 19.62 MJ

[*] Where 'g' represents the acceleration of a mass due to Earth's gravitational force (constant acceleration of 9.8 $m \cdot s^{-2}$).

for this task alone. This value has been found to be typical of the daily energy expended during military field exercises, and on the lower side of the normal range for simulated military operations (and regarded to be representative of 'operational tempo') (Tharion et al., 2005).

Davis et al., 1986 reported that when personnel, who were working at operational tempo in hot dry desert environments with the US Marine Corps, conducted tasks which involved running there was a demand for VO_2 which was in excess of 50 ml•min^{-1}•kg^{-1}. They also cited work by Goldman 1965 who had stated that the upper limit in energy expenditure for soldiers involved in combat operations in a tropical environment was 1.7 to 1.9 MJ•hour^{-1}.

Deakin et al., 2000 assessed the aerobic demand incurred (using a KB1-portable metabolic cart) by 5 male soldiers (mean age of 28 years) who each dug a shell scrape (0.6 m wide, 1.9 m long and 0.5 m depth) at simulated operational tempo. A mean VO_2 of 30.2 ml•min^{-1}•kg^{-1} was reported with the five participants working at 58.6% VO_2max (mean data). During the same study the mean aerobic demand (VO_2) of an entrenchment dig (1.8 m x 0.6 m x 0.45 m, designed by the Canadian research team as a common military task simulation) was reported to be 30.6 ml•min^{-1}•kg^{-1} (which was conducted at a mean 64.2% VO_2max for the 16 male soldiers (mean age 28 years) who participated).

A sand-bagging task (shovelling sand into sand-bags which weighed 26 to 28 kg each (dry weight) when full) within the British Army was first assessed using heart rate monitors and oxylog portable expired gas analysers by Rayson et al., 1994. They reported a mean VO_2 of 30.7 ml•min^{-1}•kg^{-1} (range 22.0 to 34.7 ml•min^{-1}•kg^{-1}) for participants at steady-state, who shovelled dry, medium-grain sand into bags which were held by a colleague at waist height, and at an undefined, self-selected pace. However these data were obtained from 4 male participants (experienced, trained British soldiers) who were subsequently using the sand-bags to construct a sand-bag sangar. These data included the physical demands of lifting the filled sand-bags to a maximum height of 1.8 m. During phase two of a project that was designed to develop evidence-based, operationally-related physical fitness standards for the Royal Air Force (RAF) Nevola et al., 2003b used the Cosmed K4b2 portable, breath-by-breath analyser to assess the aerobic demand of a standardised sand-bagging task[28] (Figure 4-6b). The specification for this task had been defined by military experts from the British Army and the RAF and exploited the information that had been obtained from the first phase of the project (which had used stable isotope analysis to quantify the energy expended during a large-scale military training exercise conducted at simulated operational tempo). Wet sand was shovelled into a bag that was held at waist height and which weighed 28 kg when filled. When 20 bags had been filled with sand, they were carried by-hand (two bags at a time) a distance of 50 m. The entire task was completed in 32 minutes. Unfortunately the mean data that were reported included the aerobic demand of carrying the sand-bags. The mean (1SD) [29] VO_2 of the task was 19.5 (8.8)[30] ml•min^{-1}•kg^{-1} (conducted at a mean (1SD) 45.6 (8.6) % VO_2max).

Construction of a shell scrape (Figure 4-6a) in wet sand (2.0 m length, 0.8 m width, and 0.3 m depth) at simulated operational tempo (shovelling rate of 20 scoops·min^{-1}) was assessed by Nevola et al., 2003b and mean (1SD) data to estimate VO_2 (from relative heart rate reserve in relationship with VO_2max) were

[28] The standardised task required participant to dig sand and fill 20 sand-bags, then carry them to location 50m from the digging position within 60 minutes. Shovel load was approximately 5.0 kg raising the load from ground position (0.0 m) to 0.5 m height, and at an average rate of 20 scoops·min^{-1}.

[29] Where 1SD described 1 standard deviation.

[30] When the aerobic demand of sand-bagging was estimated using the relationship between relative heart rate reserve and the rate of oxygen uptake for submaximal work Nevola *et al.,* 2003b reported a mean (1SD) VO_2 of 23.5 (4.4) ml•min^{-1}•kg^{-1}. The highest value for VO_2 that was observed for a single subject performing this task at a self selected work rate was 39.3 ml•min^{-1}•kg^{-1} (61.0% VO_2max), peak RPE 17.

reported as 23.3 (8.4) ml•min^{-1}•kg^{-1} (at an estimated relative work intensity of 55.3% VO_2max)[31]. The task was completed in 14.0 minutes. (For a summary of simulated criterion-test CMTs please refer to Table 4-11).

Davis et al., 1986 suggested that the US Marine Corps MOS 0311 conducted a digging task with an entrenching tool at VO_2 of 22.5 ml•min^{-1}•kg^{-1}. They also reported RPE data for US Marines who had experience of digging with an entrenching tool on jungle operations (RPE 13), cold climate operations (RPE 17), and desert operations (RPE 13). Digging with a conventional shovel was similarly rated to the entrenching tool for RPE in jungle and cold climate operations but was found to be greater when digging on operational duty in the desert (RPE 16).

Sharp et al., 1998 compiled a database of digging tasks that were conducted by MOS within the US Army. The database identified 18 tasks which represented 18 different MOS'. The reported shovel loads ranged from a minimum 4.5 kg (for 6 tasks) to a maximum 14.9 kg (for 1 task) with a mean (1SD) of 8.3 (7.5) kg. The volume of material dug ranged from 0.08 m^3 (minimum) to 5.2 m^3 (maximum), with a mean (1SD) of 1.4 (1.3) m^3. Frequency distributions for the shovel load and volume of material dug have been presented in Table 4-9 and Table 4-10.

Table 4-9: Frequency Distribution of Shovel Load (kg) During Digging Tasks in the US Army (Adapted from Sharp et al., 1998)

Shovel Load (kg)	Tasks (Number of MOS Tasks)	Proportion of all MOS Tasks (%)	Cumulative Percentage of Tasks (%)
4.5	6	33.3	33.3
9.1	1	5.6	38.9
9.5	9	50.0	88.9
11.3	1	5.6	94.4
14.9	1	5.6	100.0
Total	*18*	*100.0*	

Table 4-10: Frequency Distribution of Volume of Material Moved (m^3) During Digging Tasks in the US Army (Adapted from Sharp et al., 1998)

Volume Dug (m^3)	Tasks (Number of MOS Tasks)	Proportion of all MOS Tasks (%)	Cumulative Percentage of Tasks (%)
0.08	2	11.1	11.1
0.70	1	56	16.7
1.02	11	61.1	77.8
1.50	1	5.6	83.3
1.90	1	5.6	88.9
4.30	1	5.6	94.4
33.50	1	5.6	100.0
Total	*18*	*100.0*	

[31] The highest value for VO_2 that was observed for a single subject performing this task at a self selected work rate was 31.4 ml•min^{-1}•kg^{-1} (74.3% VO_2max).

Table 4-11: Summary of Criterion-Tasks that have been Developed to Predict Digging Performance for Civilian and Military Occupations

Criterion Task	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Test : re-test Repeatability	Source
Entrenchment dig (shovel 0.5 m^3 of dampened, crushed rock from one box to another based on trench dimensions: 1.82 m x 0.61m x 0.46 m)	Best-effort time to complete the task (seconds (s))	481 *(75th percentile)*	Infantry soldiers (Canada)	r^2 = 0.93 to 0.99	Stevenson et al., 1992; Stevenson et al., 1994
Sledge hammering (30, two-handed overhead swings with a 10-lb hammer) Simulated shovelling task (lift 20 x 15 lb shovel loads from ground (0) to 4 feet above the ground)	Best-effort time to complete the task (seconds (s))	n/a	Gas company workers (Canada)	n/a	Jamnik and Gledhill 1992
Dig a slit trench using a standard issue shovel	Best-effort time to complete the task (seconds (s))	n/a	Armed Forces (Canada)	n/a	Lee 1992
Dig a slit trench using a standard issue shovel	Best-effort time to complete the task (seconds (s))	360.0	Infantry soldiers (Canada)	r^2 = 0.86	Chahal 1993
Digging (shovel 1.0 m^3 of sand from one box to another, over a barrier using an entrenching tool)	Best-effort time to complete the task (seconds (s))	n/a	Royal Netherlands Army	r^2 = 0.81 to 0.93	Visser et al., 1996a
Digging 1-man emplacement in 45 minutes	Best-effort time to complete the task (seconds (s))	45 min	Military Occupational Speciality ECHO cluster (MOS, US Army)	n/a	Vogel et al., 1980
Construct a defensive position ~5 ft deep with en entrenching tool. A standardised task required marines to dig a fighting hole in the snow that occupied a volume equivalent to 6 large 20-gallon cans in a best-effort time (self-paced).	Best-effort time to complete the task (minutes (min))	A good time was proposed as 12 to 15 min [θ]	MOS 0311 (infantryman) US Marine Corps	n/a *this was conducted within a battery of consecutively performed criterion tasks*	Davis et al., 1986
Shovel 800 lbs of polyvinyl chloride from the floor to the top of a 3.5-foot wall, at a constant rate.	Best-effort time to complete the task (seconds (s))	n/a	Underground coal mining (USA)	n/a	Jackson et al., 1991

Criterion Task	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Test : re-test Repeatability	Source
Database of 18 digging tasks, representing 18 MOS', shovelling a mean (1SD) load of 18.2 (6.6) lbs from a mean (1SD) volume of 48.9 (45.5) ft^3 (typically digging 1.0x1.0x183.0 ft trenches to emplace piping)	n/a	n/a	US Army (laundry and shower specialists MOS 57E)	n/a	Sharp et al., 1998
Entrenchment dig (simulation of digging a one person foxhole): 1.80 m x 0.60 m 0.45 m, digging from a material composed of 1.9 cm diameter, crushed gravel (the 1999 protocol conducted in Petawawa and Halifax used pea stone)	Negative reciprocal square root of the time taken to complete the task	10 min 03 s *(developed from a study involving 207 women and 416 men where 52.7% women failed to meet this cut-off time, with only 2.9% of men failing)*	Canadian Forces	n/a	Deakin et al., 2000
Dig task (representative service task #3: digging dry sand from one box to another at a dig:rest cycle of 60 s digging (12 scoops•min^{-1} to a metronome) : 30 s standing rest for the first 12 minutes then dig at a rate of 20 scoops•min^{-1} for a further 12 minutes. A 2-minute rest was then taken and participants resumed this dig: rest protocol until volitional exhaustion (i.e. recommencing at the original, slower shovelling rate).	Time to exhaustion (minutes (min))	n/a	Royal Air Force UK (excluding aircrew)	***β*** 95% limits of agreement > 50%	Nevola et al., 2003b, Du Ross 2003
Modified (v1) dig task (representative service task #3:shovelling 0.25 m^3 of pea shingle with a spade over a barrier of 1m and from one box to another (1.15 m long x 0.87 m wide x 0.25 m deep boxes)	Best-effort time to complete the task (seconds (s))	n/a *(however, expected time limit was 10.0 minutes)*	Royal Air Force UK (excluding aircrew)	***β*** Inter class correlation = 0.937	Rayson et al., 2004a, Rayson et al., 2004b
Modified (v2) dig task (representative service task #3:shovelling 0.25 m^3 of gravel with a spade from one box to another, through a 0.2 m diameter hole at a height of 1.0 m, in a 1.2 m barrier which separated the 2 boxes (1.15 m long x 0.87 m wide x 0.25m deep boxes)	Best-effort time to complete the task (seconds (s))	n/a	Royal Air Force UK (excluding aircrew)	***β*** Inter class correlation = 0.913	Rayson et al., 2004b

β Bland-Altman 95% limits of agreement were used to describe the poor test-retest data that were obtained during this study.

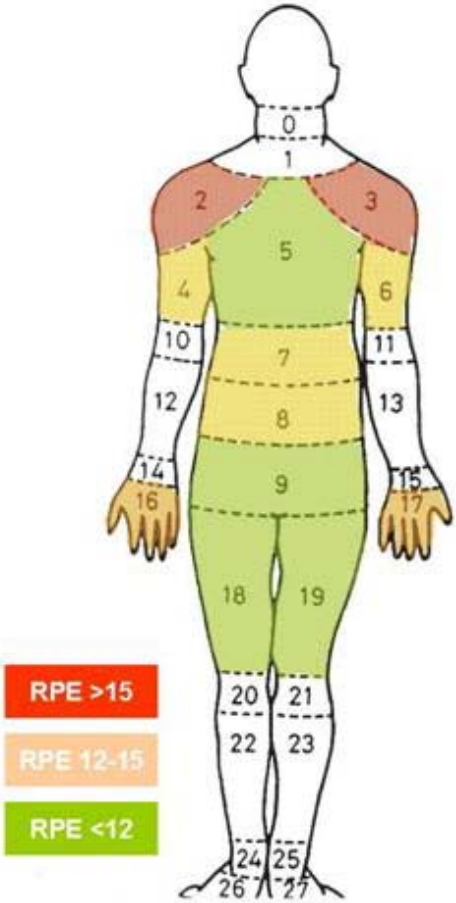
θ The defensive hole dig was performed in a mean (1SD) time of 17.2 (5.6) min (fastest: 5.0 min, slowest: 43 min).

Figure 4-10 identifies the areas of the body and the associated RPE that was reported by Royal Air Force personnel as they conducted the following common military digging tasks:

a) Sand-bagging;

b) Sangar construction; and

c) Digging a shell scrape (Nevola et al., 2003b).



AREAS OF THE BODY PERCEIVED TO INCUR THE GREATEST STRAIN (Nevola et al., 2003b)

SAND-BAGGING	SANGAR CONSTRUCTION	SHELL SCRAPE
5, 4, 6, 18, 19, 2, 3	**4, 6, 5, 7, 8, 18, 19**	**8, 9, 6**

Figure 4-10: Body Map to Locate Areas Reported to Suffer the Greatest Perceived Strain During Digging Tasks.

In 1981 NIOSH published guidelines for 'acceptable' rates of work that were considered to be 'sustainable' for an 8-hour work shift in an industrial setting. Their criteria for defining a sustainable rate of work was to recommend a threshold of 33% VO_2max as the mean work intensity during an 8-hour period. Snook and Ciriello 1991 used these guidelines to quantify, in real terms, the threshold limits for a number of work-based, criterion tasks which included lifting and pushing (physical actions that were also associated with shovelling tasks). They analysed the data from twelve women and ten men who each performed 51 variations of lifting and pushing actions[32]. From these data a series of tables were produced

[32] These actions were conducted under conditions of 21.0° dry-bulb temperature and 45% relative humidity.

which proposed threshold limits for percentiles of the normal industrial population within USA for stature and gender. Their data suggested that when the 50th percentile (stature) man was required to exert a two-handed, horizontal pushing force, at a height of 0.61 m above ground level, every 6 seconds (equivalent to a 10 scoops•min^{-1} shovelling task) throughout an 8-hour period, 31.0 kg was recommended as the threshold limit[33]. The equivalent maximum acceptable force for the 50th percentile (stature) woman[34] who performed this pushing task was 16.0 kg. Understanding these recommended limits may help to explain the variance in the findings of studies which have investigated digging performance in ground materials of different properties.

It is common for manual digging tasks to require personnel to lift the loads that are on the blade of their shovel from ground level to knuckle height. Snook and Ciriello 1991 proposed threshold limits for a sustainable rate of repetitive lifting actions (one lift every 5 seconds (12 scoops•min^{-1}) to a vertical height of 0.71 m) throughout an 8-hour shift. The maximum acceptable weight of the lift for this task when performed by a 50th percentile (stature) man was 12.0 kg (a weight that may be evident when digging with a standard 'heavy' shovel with a full load on the blade).

However no load at this high rate of lifting (one lift every 5 seconds[35]) was considered to be sustainable for an 8-hour period[36]. Maximum acceptable weight of lift for the equivalent lifting task for a 50th percentile (stature) woman[37] was 8.0 kg. Once again the guideline threshold for women was considered not to be sustainable for an 8-hour period.

4.8.1 Physiological

Deakin et al., 2000 used a KB1-C portable metabolic cart to assess the aerobic demands of a CMT (an indoor simulation of an entrenchment dig). The task simulation complied with Royal Canadian Regiment Battle School regulations for constructing a standard shell scrape. The intention was to simulate digging of a realistic shell scrape at a pace that was consistent with that required when exposed to a 'nearby enemy threat' (i.e. at operational tempo). The terrain was fairly sandy with some areas of soft clay and a few small trees. The outline for the shell scrape was marked ready to be dug (width: 0.6 m; length: 1.9 m).

When a revised version of the CMT entrenchment dig task was conducted using two adjacent boxes (see Appendix 4A-2) (one empty, the other filled with 0.486 m^3 of crushed rock) VO_2 whilst shovelling the contents of the filled box into the empty one at a self-selected pace (intended to simulate operational tempo) was an average 23.9 ml•min^{-1}•kg^{-1} (66.4% VO_2 max) for a population of female[38] Canadian Forces personnel, and 30.6 ml•min^{-1}•kg^{-1} (64.2% VO_2 max) for an equivalent population of men[39].

RPE of a CMT shovelling task for the RAF (Rayson et al., 2004b) was rated as 17 (very hard) on a scale of 6 (very, very light) to 20 (very, very hard) (Borg et al., 1973). Peak RPE data for digging actions

[33] For 10th and 90th percentile (stature) men this threshold pushing limit was 43.0 and 19.0 kg force respectively.

[34] For 10th and 90th percentile (stature) women this threshold pushing limit was 21.0 and 11.0 kg force respectively.

[35] Equivalent to a shovelling rate of 12 scoops·min^{-1}.

[36] For 10th and 90th percentile (stature) men this threshold lifting limit was 18.0 and 6.0 kg force respectively.

[37] For 10th and 90th percentile (stature) women this threshold lifting limit was 11.0 and 5.0 kg force respectively.

[38] Mean age 31 years with an average VO_2 max of 36.0 ml•min^{-1}•kg^{-1}.

[39] Mean age 28 years with an average VO_2 max of 47.7 ml•min^{-1}•kg^{-1}.

conducted during sand-bagging, digging a shell scrape and sangar building tasks were also rated as 17 during a study with RAF personnel in the UK (Nevola et al., 2003b)[40].

4.8.2 Biomechanical

Wright 1993, a captain in the British Army, studied digging and shovelling tasks that were conducted by British soldiers in the infantry and Royal Engineers during his MSc thesis. The initial 'cutting' force that was required to dig soil, with a shovel that was commonly used by service personnel, was calculated as 570 N (for the 50th percentile (body mass) soldier in the British Army), which was found to be closely correlated with data obtained from laboratory studies that Capt Wright subsequently conducted using a Kistler force platform.

Video-based analysis of the postures adopted during the construction of shell scrapes, sand-bag sangars and when filling sand-bags with dry sand during a study involving RAF personnel in the UK, found that 37.5% (minimum) to 75.0% (maximum) of the total task time was spent flexed at the waist by 90°. Only 10.0% (minimum) to 25.0% (maximum) of the total task time was spent in an upright standing posture. Digging and shovelling actions occupied from 37.5% of the total task time (sand-bagging) to 86% when constructing a sand-bag sangar (Nevola et al., 2003b).

4.8.3 Factors that Influence the Physical Demands of CMTs

Stevenson and Brown 1923 studied trench digging tasks within the Army using imagery analysis (stroboscopic photography) and expired gas analysis. They found that shovelling performance was most efficient (in terms of the time to move a volume of material) when soldiers worked at a rate of 19 to 21 scoops•min^{-1} with a throw height of <1.3 m (as shovelling performance time increased by 20% with every 1 m rise in vertical throw height above 1.3 m, and by 16% for each 1 m increase in horizontal throw distance beyond 1.2 m). Best results[41] were observed when soldiers digging the trenches first scrapped loose material onto the shovel (which had a shaft length of 0.71 m, weighed 2.27 kg, and had a blade size (area) of 0.0792 m^2) in preference to thrusting it into the target material.

The use of gloves when shovelling was found to result in an 8% increase (~0.1 kcal•kg^{-1}) in the total energy cost of performing an agricultural shovelling task (Derlitzki and Huxdorff 1927). The investigators proposed that the increased energy may be attributed to the added difficulties in securing a firm grip of the shovel when wearing the gloves as compared to an un-gloved grip.

Modifications to the shovel which effectively reduced the frictional resistance when digging into a target material was shown to reduce the total energy cost of shovelling by up to 9.5% (Vennewald 1939).

Deakin et al., 2000 cited a number of studies that had reported an increase in the energy cost of conducting various tasks as a result of the environmental conditions and the effect of different types of protective clothing that were worn by the individual. They reported a 26% increase in the energy cost of running when it was conducted over rough, forest terrain as opposed to a smooth road surface, an increase of 10% for tasks conducted in cold air temperatures as compared with performance under thermoneutral conditions, and a 15% increase in oxygen utilisation during simulated operational (combat) stress as compared with non-stress conditions. However, individual variability was high. Factors that were known to influence the rate and extent to which individuals suffered fatigue (prolonged physical activity, high relative work intensity, high levels of heat stress, dehydration, sleep deprivation, food restriction,

[40] Mean (1SD) proportion of the total time spent conducting digging or shovelling actions in the 3 of the 14 core operational tasks within the RAF was 58.6 (24.7) %.

[41] 'Best results' referred to the quickest time taken to dig the trench.

noise and vibration, etc.) had often been considered to be responsible for less efficient or poorer task performance when compared with a control condition.

Sharp et al., 1998 stated that the prime determinants of the difficulty of a digging task were the volume of material moved, and the conditions of the material (e.g. dry sand vs. frozen or rocky soil). They suggested that although it was less realistic the material used in a standardised digging task should not be influenced by changes in humidity or temperature and should present the same physical challenge to each test participant.

MOMRP 1999 reported an 8 to 18% Improvement in digging CMT performance with increased physical conditioning that could be gained from task-based physical training.

The recommendations based upon the results of a user trial conducted by Gould 1957 (where entrenching tools from the UK and USA were used as well as lightweight alternatives to the standard shovel and pick axe) stated that it was important to military personnel to dig a shelter quickly and efficiently, and that equipment that was provided to achieve this should be:

a) Acceptably low in weight;

b) Enable individual soldiers to use them;

c) Easy to use with different soil types;

d) Acceptable to the user;

e) Portable; and

f) Compatible with personal load carriage equipment.

4.9 TESTS TO PREDICT 'DIGGING' PERFORMANCE

Direct methods to assess the energy cost of physical work during military operations is problematic and (at the time of writing this chapter) has not been achieved. However, Tharion et al., 2005 summarise the data that have been obtained during several days of military (Navy, Army and Air Force) training exercises that were conducted at operational tempo and under conditions that effectively simulated operational stress for diverse missions. By reviewing the literature they were able to report a range (minimum to maximum) in energy expenditure from 13.0 to 29.8 $MJ \cdot day^{-1}$ (mean (1SD) 19.3 (2.7) $MJ \cdot day^{-1}$) that was incurred during military exercises which lasted from 2.25 to 69.0 days (mean 12.2 days). It may be suggested (arguably) that performance standards that are intended to assess an individual's ability to meet the physical demands of their operational role must also consider whether that same individual is able to sustain a rate of work which would result in such an energy expenditure within the expected time scale.

In 1976 the general accounting office (USA) recommended that the US military services developed physical fitness standards that encouraged service personnel to maintain a level of physical conditioning that afforded effective operational performance. Furthermore it was suggested that the standards should be job specific with no differentiation between men and women. Knapik et al., 2004 reviewed the research that was conducted subsequently and they described how jobs were categorised and assigned to 'clusters'. Clusters matched jobs which shared a common requirement for specific physical competencies and standards of performance. Representative tasks and criterion fitness tests were developed for each of the 5 clusters that were defined. Echo cluster (the 5th cluster which accounted for 26% of US military personnel and included 184 MOS') included a representative digging task. This digging task was conducted by individuals and entailed the use of a standard issue shovel to construct a 1-person emplacement as fast as possible (a 45-minute time limit was set). With respect to 'operational performance' it was assumed that an

individual was capable of sustaining a physical work load of up to 45% VO_2 max for an 8-hour period. Therefore, development of an operational standard (maximum aerobic power) for the most physically demanding tasks conducted by the US Army could use this assumption to recommend a standard for each cluster[42]. Gruber et al., 1965 proposed a method of screening soldiers in the US Infantry for their ability to dig 'hasty fighting positions'. Their method required individuals to perform a series of 100-yard sprints followed by a best effort time to 'excavate a specified weight of earth'. NATO working groups established a criterion military task that involved digging (Knapik et al., 2004). This task required individuals to shovel 1.0 m^3 of dry sand from one container to another in as fast a time as possible using a standard entrenching tool.

The MPFS 2000 (Deakin et al., 2000) was developed as a single standard for Canadian Forces personnel regardless of age, gender or service. A compensatory model was created for the implementation of the single standard and it was based on achieving a minimum composite score based on 6 fitness tests[43] identified as significant predictors of physical performance on 6 common emergency tasks (see Table 4-12). The composite score (ZSUM) for the compensatory model was computed as the sum of standard scores (Z-scores) for each of the 6 fitness tests (giving equal weight to each test). An appropriate performance standard was selected from data obtained by assessing a target sample of service personnel (the Target Performance Group). An overall score of 100 points or greater on the MPFS 2000 was set as a pass mark. This method allowed candidates to achieve the standard in a number of ways by trading off their strengths and weaknesses. However, in accordance with the requirements for a BFOR the MPFS standard had to avoid allowing candidates who fell short of a performance criterion that was directly linked to task success from compensating with an outstanding score in another test. Therefore, minimum passing floors were established for VO_2max (32.6 $ml \cdot min^{-1} \cdot kg^{-1}$), sit-ups (n = 15), push-ups (n = 9) and combined handgrip strength (50 kg) (see Table 4-12). Performance below the floor on any one of the 4 tests resulted in an automatic failure regardless of the overall performance. In addition, minimum Cut-off Levels (CoL) were established for the vertical jump test (0.26 m), and leg dynamometry (79 kg) whereby performances below the CoL received a score of zero points (but was not an automatic failure).

[42] For example, a task that required 8 $kcal \cdot min^{-1}$ would therefore require a maximum rate of energy production of 17.8 $kcal \cdot min^{-1}$ (i.e. 8 $kcal \cdot min^{-1}$ / 0.45) or a VO_2max of 3.6 $L \cdot min^{-1}$.

[43] The fitness tests assessed: VO_2max (20m shuttle run), sit-ups, push-ups, combined handgrip strength, vertical jump, and leg dynamometry.

Table 4-12: Summary of Physical Assessments that have been Developed to Predict Digging Performance for Civilian and Military Occupations

Physical Assessment Used to Predict Digging Performance	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Correlation to Dig Task	Source
Leg extension strength Dynamic shoulder extension endurance (10 contractions•min^{-1} at 21 kg force, repeated to exhaustion)	Force (kg) Repetitions	203.0 74.0	Infantry soldiers (Canada)	$\mathbf{r^2}$ = 0.28	Chahal 1993
Static trunk flexion VO_2max, Leg peak power	Force (kg) L•min^{-1} Power (W)	145.0 3.1 630.0	Infantry soldiers (Canada)	$\mathbf{r^2}$ = 0.36	Singh et al., 1991
Leg maximal power output, VO_2max, arm power decline, leg power decline	n/a	n/a	Infantry soldiers (Canada)	$\mathbf{r^2}$ = 0.39	Lee 1992
Isometric hand grip (sum of both hands) Sit-ups (number conducted in 1-minute) Push-ups (number conducted in 1-minute) Step test (estimate of VO_2max)	Force (kg) n n ml•min^{-1}•kg^{-1}	Men [β] / Women [β] **75** (73) / **50** (48) **19** (17) / **15** (12) **19** (14) / **13** (7) **39** (35) / **32** (30)	Infantry soldiers (Canada)	Men / Women -0.32 / -0.30 -0.04 / -0.20 -0.02 / -0.27 -0.26 / -0.16	Stevenson et al., 1992; Stevenson et al., 1994 (EXPRES)
Isometric strength (sum of several tests) Arm cranking test (estimated VO_2max)	Force (kg) ml•min^{-1}	n/a	Underground coal mining (USA)	$\mathbf{r^2}$ = 0.71 $\mathbf{r^2}$ = 0.68	Jackson et al., 1991
20 m shuttle run (VO_2max (ml•min^{-1}•kg^{-1})) Combined hand grip strength (kg) Push-ups (number) Sit-ups (number) Vertical jump (m) Leg dynamometer (kg) *(UBSD-push, and chin-ups were dropped from the test battery)*	MPFS 2000 fitness test battery	32.6 50 9 15 26 79	Canadian Forces	Men / Women $\mathbf{r^2}$ = 0.19 / $\mathbf{r^2}$ = 0.21 $\mathbf{r^2}$ = 0.02 / $\mathbf{r^2}$ = 0.06 $\mathbf{r^2}$ = 0.02 *Combining results from all tests* [44]*:* $\mathbf{r^2}$ = 0.22 / $\mathbf{r^2}$ = 0.30	Deakin et al., 2000 [45] Total sample (all participants) $\mathbf{r^2}$ = 0.64

[44] The r^2 value that was reported when regressing all test data (prior to rationalising the number of tests in the MPFS 2000 battery) with trench digging performance by Deakin et al., 2000 for men and women respectively was $\mathbf{r^2}$ = 0.26 (*men*: VO_2max, vertical jump, leg dynamometer, UBSD-push, UBSD-pull, combined handgrip, and back dynamometer) $\mathbf{r^2}$ = 0.33 (*women*: VO_2max, vertical jump, and back dynamometer).

[45] When Deakin et al., 2000 analysed the data for all of their participants (i.e. pooling data for men and women) those test variables which afforded the greatest predictive power for the trench digging task were as follows: (1st) VO_2max; (2nd) combined hand grip; (3rd) upper body strength device (UBSD-push); (4th) back dynamometer; (5th) chin-ups; (6th) leg dynamometer.

Physical Assessment Used to Predict Digging Performance	Measure (Unit)	Cut-off Standard (Pass/Fail)	Occupational Population (& Nation)	Correlation to Dig Task	Source
Hill dash time (min) (*150 m sprint up a 6% incline*) Sit-ups (n) 3-mile run time (min) long jump (m) perceived exertion (RPE)	min n min m RPE (6 to 20 scale (Borg 1973))	n/a	US Marine Corps (MOS 0311 Infantryman)	0.79 -0.58 0.42 -0.42 0.4	[46]Davis et al., 1986
Isometric muscle strength (5 muscle groups) Vertical jump test Body fat Cyclo-ergometry (estimated VO_2max)	n/a	n/a	n/a	n/a	Bertina 1997 ('Assessment of Physical Capabilities' APC)
Entrance tests Step test (Heart rate) Upright pull (kg) *On-the-job tests* 2-mile run (min) Push ups (n) Sit-ups (n) Squat thrusts (n)	(As indicated in brackets)	n/a	MOS ECHO cluster (US Army)	n/a	Vogel et al., 1980

[46] US Marines in the original research conducted each critical task one after the other with only a 2-minute rest between tasks. Performance time was taken for completion of the entire battery of critical tasks under conditions of cold weather/high altitude following acclimatisation. Standardised canonical coefficients of physical fitness test data to performance on the battery of critical tasks have been reported (the *defensive fighting hole dig task* had a reported canonical correlation coefficient of 0.39 with the task battery).

Deakin et al., 2000 performed separate principal component analyses with varimax rotations on their CMT and fitness test data for their male vs. female participants. It was found that the pattern of test variable loadings was the same for men and women, which provided evidence of similar correlation patterns among the tests between men and women despite the differences in performance level. This finding was interpreted by Deakin et al., 2000 to further justify the development of a single minimum physical fitness standard for men and women.

When RAF personnel conducted a shovelling CMT the results of a questionnaire to assess the relevance of the CMT to task-based, operational requirements found that the majority of participants acknowledged that use of a digging CMT was an effective method to discriminate between individuals who were capable of conducting core operational tasks from those who were incapable (Rayson et al., 2004b). Furthermore, RAF personnel who had experience of working on operations reported that the digging CMT that was used by the RAF was indeed an effective means of discriminating between those individuals who were capable of digging a slit trench from those who were not capable (Rayson et al., 2004a).

4.9.1 Content (Criterion-Based Tests and Simulations)

One of the studies that was conducted by Deakin et al., 2000 assessed the performance of 623 participants (416 men and 207 women)[47] on an entrenching dig CMT[48]. Participants were representative of military personnel in the Canadian Forces with respect to physical fitness for each of 4 quartile ranges in age[49], and who afforded equal representation across the three services (Army, Navy and Air Force). Best effort times (mean (1SD)) for digging the 0.486 m^3 volume of crushed rock were 11 min 11 s (4 min 12 s) for women[50], and 5 min 445 s (1 min 41 s) for men. There were significant disparities between male and female performance scores on most of the MPFS 2000 tests and CMT tasks.

Pearson product moment correlation between fitness test and CMT performance ranged in absolute value between 0.42 and 0.89 ($p<0.001$) when gender was combined (it was generally found that when correlation between fitness test and CMT performance was assessed separately for men and women there was a much larger variance). Deakin et al., 2000 found that performance on one of the 5 CMTs was more closely correlated to performance on another CMT than any single fitness test. They explained that this was probably due to the proximity of the physical abilities that each CMT required in order to achieve the desired performance.

When men performed the entrenchment dig CMT (Deakin et al., 2000) the closest correlations were reported for:

a) VO_2max ($r = –0.44$);

b) CMT sea evacuation ($r = 0.55$);

c) CMT land evacuation ($r = 0.53$): and

d) CMT low/high crawl ($r = 0.43$).

When women performed the entrenchment dig CMT the closest correlations were reported for:

a) VO_2max ($r = –0.46$);

[47] The age range of the total sample was 19 to 53 years.

[48] The entrenchment dig was intended to simulate *'self protection in the face of the enemy'* and each subject was required to dig a 1.8 m long, 0.6m wide, and 0.45 m deep trench using a standard shovel. The ground material was a fixed amount of crushed rock which was transported from one box to another and completed in a *best effort* time.

[49] Age categories were: (a) 29 years and under; (b) 30 to 33 years; (c) 34 to 37 years; and (d) 38 years and over.

[50] Performances ranged from fastest to slowest were: 5 min 52 s to 28 min 45 s for women; and 3 min 32 s to 14 min 40 s for men.

b) CMT sea evacuation (r = 0.55);

c) CMT land evacuation (r = 0.54): and

d) Vertical jump test (r = –0.45).

Visser et al., 1996 assessed a digging task which had been designed to simulate work that was commonly undertaken by the Armed Forces within the Netherlands. Their digging task involved shovelling 1.0 m^3 of dry sand from one box to another, over a barrier. This was a best-effort, timed task and performances averaged approximately 21 minutes[51]. Male participants tended to record an improved performance time (by approximately 36 seconds) on their second attempt at this task when compared with their initial time. When performance times for the two attempts at this task by each participant were compared, correlation coefficients (and coefficient of variation (%)) for the men, women and grouped data were 0.81 (6.1%), 0.94 (4.1%) and 0.93 (5.4%) respectively.

(a) (b)

Figure 4-11: An Example (a) of a Soldier Conducting a Digging Task in the Canadian Forces, and (b) the Subsequent Slit Trench Digging Task that was Initially Developed.

Nevola et al., 2003a identified digging as an action that was essential to several 'core' tasks that had been agreed by subject matter expects to be requirements of the 'generic' operational role for RAF personnel. They later defined the specification of the tasks that required digging and subsequently analysed the associated physical demands (Nevola et al., 2003b). The results of a notational analysis of the actions conducted during 3 of the fourteen core operational tasks (matched to their physical demands) enabled Nevola et al., 2003b to design a Representative Service Task (RST) (content-based) that could be used to establish evidence-based, physical fitness standards for RAF personnel. One of the four RSTs targeted digging/shovelling performance and involved shovelling 0.5 m^3 of sand (this volume equated to that required to fill 20 sand-bags or an individual's expected quota (within a team of four personnel) when

[51] Men on average completed the task in 21 minutes, whilst women took 32 minutes to dig the 1.0 m^3 of sand.

digging a sand-bag sangar or trench). During a follow-on study that was conducted at RAF Marham (UK) involving 33 male and 4 female RAF personnel[52] Du Ross 2003 assessed the repeatability[53] of all four RSTs that had originally been proposed by Nevola et al., 2003b.

It was recommended that the format of the digging RST (Figure 4-12) was revised (Figure 4-13) in order to reduce the test vs. re-test variability and to reduce the risk to the participant of incurring a back injury (i.e. to conform to existing health and safety requirements).

Figure 4-12: The Original Protocol for the Representative Service Task Digging Conducted During the Assessment of 'Repeatability' by Du Ross 2003.

[52] These personnel (mean (1SD) age 26.6 (6.7) years; height 1.74 (0.09) m; body fat 18.7 (7.4) %; Hand grip strength 47.0 (9.1) kg) were eligible for deployment on operations with the RAF, they were familiar with the core operational tasks, and they included *junior* (aircraftsman) to *senior* (squadron leader) ranks. Sixty-three percent of the participants had shovelled sand into sand-bags on operations and forty-one percent had experience of digging whilst on deployment.

[53] Repeatability was assessed for test vs. re-test data for the same participants conducting the same RSTs. Pearson product moment correlation, coefficient of variation and Bland-Altman 95% limits of agreement were calculated for data on 3 successful repetitions of the RSTs.

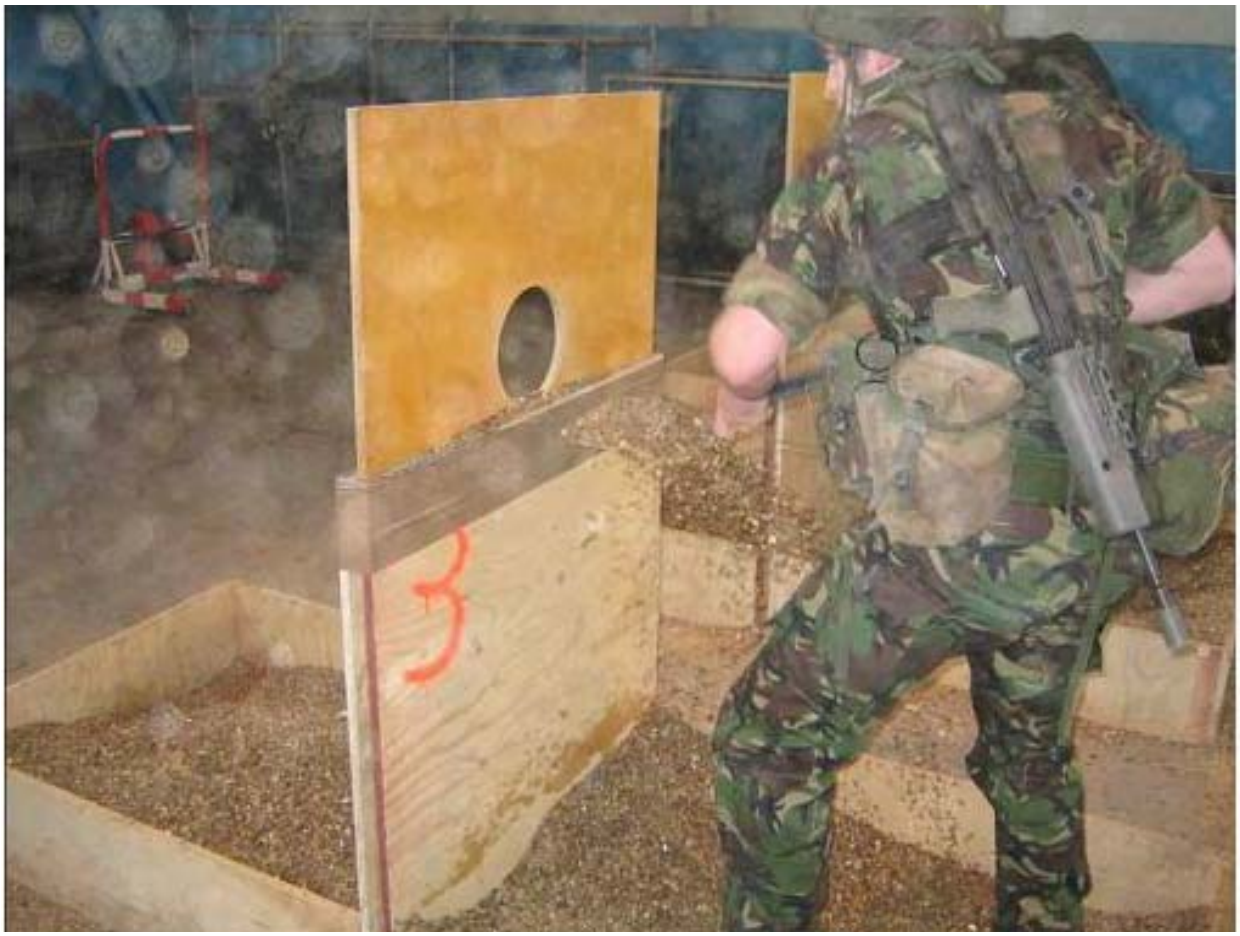


Figure 4-13: The Modified (v2) Protocol for the Representative Service Task Digging Conducted During the Assessment of 'Repeatability' by Rayson et al., 2004a.

In its original format the digging RST required participants to wear full operational clothing (including webbing, helmet and the weapon secured to the back by a sling[54]) whilst shovelling dry sand from one large container (2 m x 2 m grid) to another (2 m x 2 m grid). Participants commenced shovelling at a rate of 12 scoops•min^{-1} (in time with pre-recorded metronome bleeps)[55] for 60 seconds and then stood rested for the next 30 seconds. This work : rest cycle continued for 12 minutes after which the rate of work increased to 20 scoops•min^{-1} for a further 12-minute period. At the end of this period participants rested for 2 minutes before re-commencing the entire 24-minute routine.

This continued until participants could no longer maintain the desired work rate, or until they requested to stop. Performance was assessed by the length of time that the RST was conducted for each participant. Unfortunately complete sets of data were obtained for only 6 male participants, which raised doubt concerning the legitimacy of the analysis to assess this RST. A negative correlation coefficient was reported as a result of participants recording their best performance times on their first attempt at the RST. Poor 'reliability/repeatability' was attributed to changes in the environmental conditions between test vs. re-test, learning effects, fatigue, and a lack of standardisation in the shovelling techniques that had been used by the participants. Du Ross 2003 recommended that the RST digging protocol was modified and re-assessed in-doors during a larger study.

[54] The total load added to the participant's body mass was approximately 20 kg.

[55] However the blade load was not standardised.

The modified (v1) RST digging task involved shovelling 0.25 m^3 of dry pea shingle over a 1.0 m high barrier from one container (1.15 m long x 0.87 m wide x 0.25 m high) to another of similar dimensions, using a spade in a best effort time (Rayson et al., 2004a). Data from 43 participants at RAF Honnington (UK) (representing of a range of trades within the RAF) were obtained for performance on the modified (v1) digging RST conducted on 3 occasions over a 2-week period.

Heart rate was recorded every 5 s throughout each RST and participants provided a rating of their perceived exertion (RPE (Borg 1973)) immediately following completion of each RST performance. Rayson et al., 2004b described a statistically significant bias in the data between the three performances of the modified (v1) digging RST. Participants significantly improved their test times[56] with each subsequent modified (v1) digging RST performance (test 1: mean (1SD) 593 (162) seconds; test 2: 511 (140) s; test 3: 478 (128) s). Analysis of the effect of RAF trade on performance time was not statistically significant ($p = 0.223$) and cardiovascular strain between repetitions of the modified (v1) digging RST showed no significant difference in mean heart rate data. When comparing test 1 to test 3 performance times the Intraclass Correlation Coefficient (ICC) was 0.937. However, Bland-Altman 95% limits of agreement were 163 s or 30.9% which Rayson et al., 2004b described as being unsatisfactory when seeking reliability/repeatability in test data. It was concluded that modified (v1) digging RST demonstrated poor reliability and substantial improvements in performance occurred with subsequent re-tests. Further modifications to the RST protocol were recommended.

In an attempt to eliminate the learning effect between test performances modified (v2) digging RST was proposed and a small study was conducted to assess its reliability (Rayson et al., 2004b). The modified (v2) digging RST entailed shovelling dry gravel through the centre of a hole (0.2 m diameter)[57] (see Figure 4-13) which stood at the 1.0 m point in a 1.2 m vertical barrier that separated two containers of equal dimensions (1.15 m long x 0.87 m wide x 0.25 m deep). Fourteen participants from the RAF (11 men and 3 women) performed this modified (v2) digging RST on 3 occasions within a 5 day period. The results were similar to the previous study for the modified (v1) digging RST.

There was a statistical bias between test performances ($p<0.001$) with an average 13.4% improvement between test 1 and test 2 ($p = 0.006$). However, the improvement in performance time between test 2 and test 3 (7.8%, $p = 0.073$) did not reach statistical significance[58]. The ICC was 0.913 with a 95% limits of agreement of 250 s (or 34.2%)[59]. Analysis of heart rate data collected during the tests (and used as a method of assessing the cardiovascular strain during each test performance) found no difference in mean heart rate between tests ($p = 0.67$). Rayson et al., 2004b suggested that the improvement in test times was attributed to a skill learning effect and was not related to any difference in physical effort or strain between tests.

Rayson et al., 2004b concluded that the digging RST (all versions) had poor reliability. No plateau in performance times had been observed within any of the tests and repetitions, which was interpreted as evidence that a reliable result could not be achieved without at least two or more full practice sessions (for complete familiarisation with the test protocol).

[56] Mean improvement of 82 seconds (or 13.8%) between test 1 and test 2 ($p<0.01$), and 33 seconds (6.5%) between test 2 and test 3 ($p = 0.01$).

[57] The intention of shovelling through a hole was to prevent participants from throwing the gravel in an uncontrolled manner, over the barrier. It was hoped that this approach would ensure that each shovel load would be deposited in a more purposeful and consistent manner (reducing inter- and intra-variability in shovelling technique).

[58] It is possible that this may in-part have been due to the relatively small sample size. A power calculation was not conducted for this study.

[59] Test results were as follows (mean (1SD)): *test 1*: 820 (231) s; *test 2*: 710 (194) s; *test 3*: 654 (138) s.

Additional research has been conducted (at the time of writing this chapter) which targeted approximately 50 to 100 RAF participants from a range of trades and specialisations. A further revision to the v2 RST protocol was developed which used a reduced volume (0.125 m^3) of moistened pea gravel (for reasons of health and safety). The draft performance standard for this RST was considered by an expert 'select' panel, and one suggestion proposed an interpretation of data from the previously reported physical demands analyses (Nevola et al., 2003a and b)[60].

Stevenson et al., 1992 assessed the performance of military participants (66 men and 144 women under the age of 35 years) on several CMTs and physical fitness tests, during a 3-year study to develop physical performance standards for the Canadian Armed Forces. An entrenchment dig task (see Table 4-11) was designed and used within the study. Participants completed the best effort entrenchment dig task[61] in a mean (1SD) time of 252.8 (49.8) s (men) and 507.8 (133.9) s (women). Test, re-test correlation to assess repeatability was reported to be r = 0.99. Pearson product moment correlation coefficients for EXPRES test results with entrenchment dig task performance were:

Men: (a) –0.26 (VO_2max); (b) –0.32 (maximum handgrip strength);

(c) –0.04 (sit-ups); and (d) –0.02 (push-ups);

Women: (a) –0.16 (VO_2max); (b) –0.30 (maximum handgrip strength);

(c) –0.25 (sit-ups); and (d) –0.27 (push-ups).

A common (i.e. same for men and women) cut-off score for the entrenchment dig task was proposed by Stevenson et al., 1992 and accepted at the 75th percentile (performance score) of the representative sample, as 481 seconds (or 8 minutes). Fifty percent of women who were tested were unable to achieve (or better) this cut-off score, whilst 100% of men met this performance threshold.

4.9.2 Construct (Indirect Tests to Predict CMT Performance)

(See Table 4-12 for a summary of the data reported in the available literature).

Performance tests (construct-based) that have often been used by the military to screen trained personnel or new recruits, tend to have been quick and easy to implement gym- or field-based tests that were economical to administer in terms of time and resources. As such they tended to provide a broad estimate of the physical construct that was being targeted (e.g. use of the 20 m shuttle run test to assess aerobic power). Test, re-test reliability has been a critical factor when evaluating the efficacy with which the physical abilities of individuals may be appropriately classified (Deakin et al., 2000). Aerobic power has been regarded as the single best indicator of physical fitness and an important determinant of physical work capacity (Åstrand and Rodahl 1986) for physically demanding occupations. Research has been conducted to ensure that the popular 20 m shuttle run test afforded acceptable test, re-test reliability (r = 0.95, p>0.05) and a reasonably accurate[62] prediction of aerobic power when compared with the gold standard measure (Léger and Gadoury 1989). Deakin et al., 2000 conducted a stepwise regression analysis to compare fitness test data with CMT performance. Estimated VO_2max from a 20 m shuttle run test to

[60] On the basis that 100 scoops were required to transfer 0.125 m^3 of moistened pea gravel using a general service spade, and that the mean rate of shovelling during the study by Nevola et al., 2003b observed RAF personnel working at 14 $scoops \cdot min^{-1}$ (minimum: 6 $scoops \cdot min^{-1}$; maximum 20 $scoops \cdot min^{-1}$) at operational tempo, an option existed for a performance standard of (100 scoops / 14 $scoops \cdot min^{-1}$) 7 minutes 8.5 seconds. However, a robust validation process was required with the necessary impact analysis (including rates of misclassification for RST vs. core operational task performance).

[61] Shovelling 0.5 m^3 of dampened, crushed rock from one 1.82 m long x 0.61 m wide x 0.46 m deep container to another.

[62] In a study by Bilzon et al., 2000 it was reported that the size of the 95% confidence interval for the 20-m shuttle run test may reflect an observed performance range (for an individual with a $\dot{V}O_2$max of 41 $ml \cdot min^{-1} \cdot kg^{-1}$) from level 6 shuttle 3 to level 10 shuttle 4.

volitional exhaustion was found to be the best individual test predictor of task time for the entrenchment dig (CMT) for both male and female participants[63]. When the results of 6 fitness tests were compared with CMT entrenchment dig performance for the entire sample (combining the data from male and female participants) $r^2 = 0.64$. The second most important predictor of the entrenchment dig task was combined hand grip strength. The test, re-test reliability of performance tests[64] were reported for handgrip strength ($r = 0.84$), sit-ups ($r = 0.85$), and push-ups ($r = 0.98$) (cited in Deakin et al., 2000).

Lee 1992 obtained performance data from 99 male soldiers in the Canadian infantry who conducted a series of physical fitness tests and a task which involved digging a slit trench using a General Service shovel. Stepwise multiple linear regression analysis was used to design an equation to predict digging task performance for these participants from a combination of 'best predictor variables' within the battery of fitness tests. Lee 1992 reported a correlation of $r^2 = 0.39$ when data from tests to assess maximal leg power output, maximum aerobic power, arm decline power, arm peak power and leg power decline were used to predict digging task time. Chahal 1993 followed-on from Lee 1992's research incorporating measures of body composition, muscle strength and muscle endurance. Analysis of data from 116 soldiers in the Canadian infantry afforded a test, re-test reliability for the slit trench digging task of $r^2 = 0.86$. During this study an equation to predict trench digging task performance used a combination of results from leg extension strength, and tests of dynamic shoulder extension endurance ($r^2 = 0.28$)[65]. Cut-off scores (minimum acceptable performance) were proposed for the slit trench digging task and the associated criterion physical fitness tests (slit trench digging task time: 360 seconds; leg extension strength: 203 kg; dynamic shoulder extension endurance: 74 repetitions (see Table 4-12)). Further development of the physical performance standards for the Canadian infantry found that maximum aerobic power, static trunk flexion and leg peak power afforded the best prediction of slit trench digging task performance ($r^2 = 0.36$ (Singh et al., 1991)). Revised cut-off scores were recommended for the criterion tests that best predicted trench digging task performance[66].

Stevenson et al., 1992 continued the progress of developing BFOR performance standards for Canadian Forces by designing the EXPRES[67] program. An entrenchment dig task was used (see Table 4-11) as a BFOR test against which criterion physical fitness tests were assessed. Subsequent studies which had investigated performance standards for two age categories (individuals younger than 35 years separate from individuals who were 35 years or older) had used an upper limit of 'allowable' heart rates to achieve during the tasks and criterion tests. When the restrictions on allowable heart rate limits for participants (100 men, 66 women) who were aged 35 years or older were removed a 38% improvement in entrenchment digging task performance was observed.

Separate equations for men (n = 137 male soldiers) and women (n = 61 female soldiers) were developed by Visser et al., 1996 to predict performance of a criterion digging task for the Royal Netherlands Army. The results of tests to assess maximum aerobic power (cyclo-ergometry), static leg extension strength, fat free mass and 12-minute run distance afforded the highest correlation with the criterion digging task for men ($r^2 = 0.30$). However, the combination of test data that afforded the best correlation with the criterion digging task for women ($r^2 = 0.45$) were fat free mass, estimated maximum aerobic power (arm-ergometry), elbow flexion isometric strength, and estimated maximum aerobic power (cyclo-ergometry).

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[63] However overall correlation for the best combination of fitness test scores and entrenchment dig performance produced an $r^2<0.34$ when data for men and women were assessed separately.

[64] Sometimes referred to as *'physical abilities testing'*.

[65] Standard error of estimate was 38 seconds for the time to complete the slit trench digging task.

[66] Cut-off scores recommended by Singh et al., 1991 were: VO_2max 3.1 $L \cdot min^{-1}$; leg peak power 630 Watts; static trunk flexion 58 kg.

[67] EXPRES test was the Canadian Standardise test of fitness known as the exercise prescription test.

4.9.3 The Relationship Between CMT, Criterion-test and Job Performance

In order to assess the relationship between CMTs, fitness (or criterion) tests and the physical demands of the occupational tasks Deakin et al., 2000 reviewed the results of their preliminary studies and designed a validation study for their selected 'target performance group' (these were participants whose VO_2max was 39.4 ml•min^{-1}•kg^{-1} or higher). They established their physical fitness standard on the basis of the performance levels of this target performance group. They sought to develop a single fitness standard using a compensatory model on the basis that an individual participant may not have great physical strength but might have a very high aerobic power which may allow for successful completion of tasks by using alternative legitimate techniques.

The target performance group (TPG) consisted of 321 men (mean (1SD) aged: 31.1 (6.2) years; body mass: 80.1 (9.9) kg; VO_2max: 46.6 (4.2) ml•min^{-1}•kg^{-1}) and 42 women (mean (1SD) aged: 30.6 (6.1) years; body mass: 62.3 (8.1) kg; VO_2max: 42.7 (2.3) ml•min^{-1}•kg^{-1}) from the Canadian Forces[68]. The performance times of this group when conducting a CMT entrenchment dig task were as follows:

	n	Mean Time (min : s)	1SD (min : s)	Coefficient of Variation (%)
Men	*321*	5 : 27	1 : 27	26.6
Women	*42*	8 : 46	2 : 11	24.9
Entire group	*363*	5 : 50	1 : 53	32.3

Deakin et al., 2000 opted for a ZSUM model[69] in preference to a CANTEST approach when developing their criterion target scores and subsequent performance standard. They compared the number of participants within the TPG who passed and failed on ZSUM scores at both 1.5 and 2.0 standard deviations from the mean. It was found that although there was little difference in the CMT performance scores between the ZSUM quantiles at mean ($\tilde{x}$) minus 1.5 versus mean minus 2 standard deviations, there was a large impact on the percentage of women passing the fitness criterion tests (10% pass at $\tilde{x}$-1.5SD, versus 20% pass at $\tilde{x}$-2.0SD). On the basis that there was no demonstrable improvement on CMT performance scores between $\tilde{x}$-1.5SD and $\tilde{x}$-2.0SD Deakin et al., 2000 selected the more lenient criterion of $\tilde{x}$-2.0SD. Cut-off scores and floor values were established for the MPFS criterion tests such that individuals who were assessed possessed the essential physical competencies that were evident from the physical demands analysis of CMTs. Gold standard passing levels were also recommended for each of the CMTs. The CMT entrenchment dig was assigned a gold standard pass score of 10 min 03 s (which resulted in 2.9% of men (n = 416) and 52.7% of women (n = 207) in the target performance group failing to meet this standard).

[68] The entire sample of 363 participants had mean (1SD) age: 31.1 (6.2) years; body mass: 78.1 (11.2) kg; VO_2max: 46.2 (4.2) ml•min^{-1}•kg^{-1}.

[69] The pass score (referred to as the MPFS 2000 score) using the ZSUM model was calculated as ((ZSUM + 18) x 6.784) and has a single passing score of100 points which has been summed from the performance on each of the criterion fitness tests.

Table 4-13: Summary of Research that has been Conducted within NATO to Develop Physical Assessments which Predict CMT or Criterion Task Performance for Occupations with a BFOR to Dig

Criterion test or CMT	Predictor Variables	Relationship to CMT	Occupational Population (& Nation)	Sample Size	Men (M) / Women (W)	Source
Shovelling earth and slag	Isometric arm test	r^2 = 0.67 to 0.72	Steel workers (USA)	n/a	n/a	Arnold et al., 1982
Sledge hammering Simulated shovelling task	Aerobic power (physical demands of shovelling: 1.2 to 3.3 L•min^{-1}, or 28 to 79% VO_2max)	2.0 to 2.7 *Likert scale 1 (best fit to CMT) to 7 (no fit to CMT)*	Gas company workers (Canada)	n/a	n/a	Jamnik and Gledhill 1992
Dig a slit trench using a standard issue shovel	Leg maximal power output, VO_2max, arm power decline, leg power decline	r^2 = 0.39	Infantry soldiers (Canada)	99	***n/a***	Lee 1992
Dig a slit trench using a standard issue shovel	***n/a***	r^2 = 0.28	Infantry soldiers (Canada)	116	***n/a***	Chahal 1993
Slit trench digging	That maximum aerobic power, static trunk flexion and leg peak power	r^2 = 0.36	Infantry soldiers (Canada)	**n/a**	45 W	Singh et al., 1991
Dig one man emplacement in 45 minutes	Entrance (1) Heart rate from step test and %body fat (2) 38-cm upright pull Maintenance (1) 2-mile run (2) Push ups (3) Sit ups (4) Squat thrusts	***n/a*** ***(Standards: Aerobic fitness < 1.5 L·min^{-1}; Strength <30 kg to lift from ground to waist height)***	Echo cluster (56% of all MOS', ~26% of all US Army)	228	184 M, 44 W	Vogel et al., 1980
Digging sand	Models were based on muscle strength and aerobic endurance	r^2 = 0.3 M r^2 = 0.45 W	Netherlands Armed Forces (Army)	188	137 M, 61 W	Visser et al., 1996a
Entrenchment dig	Isometric hand grip Sit-ups Push-ups VO_2max	r^2 = 0.14 to 0.48 M r^2 = 0.14 to 0.41 W	Canadian Forces	210	66 M, 144 W (aged <35 years)	Stevenson et al., 1992

Criterion test or CMT	Predictor Variables	Relationship to CMT	Occupational Population (& Nation)	Sample Size	Men (M) / Women (W)	Source
Entrenchment dig	Isometric hand grip Sit-ups Push-ups VO_2max	$r^2 < 0.49$M $r^2 < 0.55$ W	Civilians and soldiers (Canada)	166	100 M, 66 W (aged >34 years)	Stevenson et al., 1992

4.10 TRAINING TO IMPROVE 'DIGGING' PERFORMANCE

No direct evidence could be found within the available literature to describe a physical training regime that had been designed with the necessary specificity with which to improve digging performance (during CMTs). However, it may be reasonable to assume that those physical constructs (i.e. aerobic power, and isometric arm strength and endurance) which had been shown to best predict CMT (digging) performance would be prominent within such a task-specific training regime. This assumption remains to be established.

4.11 CONCLUSIONS

Bona Fide Occupational Requirements (BFOR) or 'military occupational specialities' (or their equivalent) have been adopted by the Armed Forces to match personnel to the work that they are physically capable of performing, and to define specific training requirements which best prepare individuals to meet the demands of their operational military role. Historically, the establishment of a BFOR has tended to involve the identification and analysis of the most physically demanding, common military tasks (CMTs). Digging and shovelling actions have been shown to be essential requirements of such CMTs. A summary of CMTs involving digging and shovelling has been provided. The physical demands of digging and shovelling tasks have been investigated and a review of the literature was discussed within this chapter. It was shown that the energy cost of digging and shovelling was influenced by factors such as:

a) Throw height and distance;

b) Blade size and shape;

c) Shovelling rate and blade load;

d) Posture and technique;

e) Nature of the material displaced;

f) The physical state and anthropometry of the individual;

g) Lift angle; and

h) The design of the shovel.

A light-weight shovel with a relatively large-sized blade, and a blade to weight ratio of approximately 0.0676 $m^2 \bullet kg^{-1}$ has been shown to provide the criteria which define the most efficient shovelling of a sand-like material. Digging with a blade that was too large or with a shovel that was too heavy has been shown to increase the rate of energy expenditure (above 21.6 $KJ \bullet min^{-1}$ which has been considered to be the optimum, sustainable rate for an 8-hour work shift) and reduce shovelling efficiency (as it has been shown that very little useful work was subsequently produced). The material properties of the shovel (e.g. density of the metal used to construct the blade) influence the blade to weight ratio which affords the optimum use of energy for a given shovelling task.

Research has been conducted to identify methods of assessing the physical ability of military personnel to meet the demands of digging and shovelling CMTs. However, the reported reliability of such protocols, when screening for digging-based abilities, has been variable (ranging in r^2 from 0.81 (worst) to 0.99 (best)) and lacks adequate agreement with CMT performance (ranging in r^2 from 0.14 (worst) to 0.72 (best)). Association with lower back injuries and the lack of validity as discriminator tests has often resulted in the withdrawal of digging-based tests from screening protocols. However, research and development to establish valid CMT simulations (which involve digging) and associated gym-based tests continues within the Armed Forces of NATO.

4.12 REFERENCES

[1] Army code no. 71271 (Pam 2). (1993). Field Fortifications. Military Engineering Volume II Field Engineering pamphlet no 2. UK Army.

[2] Åstrand, Per-Olaf and Rodahl, K. (1986). Textbook of work physiology: physiological bases of exercise (third edition). McGraw-Hill International Editions, Medical Series, New York, USA.

[3] ATP-52(A). (1997). Land Force Combat Engineer doctrine, (NATO UNCLASSIFIED).

[4] Ayoub, M.M., Bethea, N.J., Bobo, M., Burford, C.L., Caddell, K., Intaranont, K., and Morrissey, S.J. (1981). Mining in low coal. Contract no. HO387022, US Bureau of Mines.

[5] Ayoub, M.M. and Lopresti, P. (1971). The determination of optimum size cylindrical handle by use of EMG. *Ergonomics*, 14: 509.

[6] Bilzon, J.L.J., Scarpello, E.G., Smith, C.V., Ravenhill, N.A. and Rayson, M.P. (2000). Characteristics of the metabolic demands of shipboard Royal Navy fire-fighting tasks. An interim report. Institute of Naval Medicine Report No. 99067.

[7] Borg, G.A. (1982). Psychological bases of perceived exertion. *Med Sci Sports Exerc,* 14 (5): 377-381.

[8] Borg, G.A.V. (1973). Perceived exertion, a note on 'history' and methods. *Medicine and Science in Sports,* 5: 90-03.

[9] Bridger, R.S., Cabion, N., Goedecke, J., Rickard, S., Schabort, E., Westgarth-Taylor, C. and Lambert, M.I. (1997). Physiological and subjective measures of workload when shovelling with a conventional and two-handled ('levered') shovel. *Ergonomics*, 40 (11): 1212-1219.

[10] Briosi, G.K. (1980). Conceivable approaches to rapid digging by the individual soldier (U). DRES Suffield Technical Note, Ralston, Alberta. Project 27C99.

[11] Brouha, L. (1960). Evaluation of industrial stresses by the physiological reactions of the worker. *Physiology in Industry*. Permagon Press, London.

[12] Carrasco, C., Lusted, M. and McPhee, B. (1992). Evaluation of three variations in shovelling coal. Proceedings of the 28th annual conference in Ergonomics, 258-265.

[13] Chaffin, D.B. and Baker, W.H. (1970). A biomechanical model for analysis of symmetric sagittal plane lifting. *Transactions of the American Institute for Industrial Engineers*, 2: 16-27.

[14] Chahal, H.S. (1993). Army physical fitness performance standards based on body composition, muscular strength and endurance. Edmonton Alberta, Canada, University of Alberta Dept of Physical Education and Sports Studies. PhD dissertation.

[15] Chakraborty, M.K., Sensarma, S.K. and Sarker, D.N. (1974). Blood lactic acid in determining the heaviness of different mining work. *Indian Journal of Physiological Pharmacy,* 18: 341-348.

[16] Constable, S. and Palmer, B. (Eds). (2000). The process of physical fitness standards development. State of the Art Report, Human Systems Information Analysis Center, Wright-Patterson Air Force Base, Ohio, USA.

[17] Davis, P.O., Dotson, C.O. and Sharkey, B.J. (1986). Physical fitness requirements of United States Marine Corps MOS 0311. Institute of Human Performance, New Hampshire, Technical Report contract number N00014-80-C-0473.

[18] Deakin, J.M., Pelot, R.., Smith, J.T. and Weber, C.L. (2000a). Minimum Physical Fitness Standard (MPFS) for Canadian Forces personnel. Technical Report by the Ergonomics Research Group, Selection and Maintenance Standards Division, Queens University, Canada.

[19] Deakin, J.M., Pelot, R., Smith, J.T. and Weber, C.L. (2000b). MPFS test manual and technology transfer. Supplement to Minimum Physical Fitness Standard 2000 final report. Ergonomics Research Group, Selection and Maintenance Standards Division, Queens University, Canada.

[20] Degani, A., Asfour, S.S., Waly, S.M. and Koshy, J.G. (1993). A comparative study of two shovel designs. *Applied Ergonomics*, 24(5): 306-312.

[21] Drillis, R.J. (1963). Folk norms and biomechanics. *Human Factors*, 5: 427-441.

[22] Du Ross, J. (2003). The reliability and validity of representative service tasks for the Royal Air Force. A thesis submitted in part fulfilment for the award of Master of Science in sports and exercise, Loughborough University of Technology, UK.

[23] Fathallah, F.A., Marras, W.S., Parnianpour, M. and Granata, K. (1997). A method for measuring external spinal loads during unconstrained free-dynamic lifting. Journal of Biomechanics, 30: 975-978.

[24] Freivalds, A. (1986). The ergonomics of shovelling an shovel design – a review of the literature. *Ergonomics*, 29(1): 3-18.

[25] Freivalds, A. (1986b). The ergonomics of shovelling and shovel design – an experimental study. *Ergonomics,* 29(1): 19-30.

[26] Freivalds, A. and Kim, Y.J. (1990). Blade size and weight effects in shovel design. *Applied Ergonomics*, 21(1): 39-42.

[27] Gledhill, N. and Jamnik, V.K. (1992). Development and validation of a fitness screening protocol for fire-fighter applicants. *Can J Sports Sci,* 17: 199-206.

[28] Gould, A.H. (1957). User trials of the comparative efficiency of entrenching tools and lightweight picks and shovels. Army Operational Research Group Memorandum No.H.5.

[29] Granati, A. and Busca, L. (1941). Il costo del lavoro nelle miniere di carbone in carbonia. *Quaderni della Nutrizione*, 8: 1-34.

[30] Grandjean, E. (1971). Fitting the Task to the man. Taylor and Francis, London.

[31] Gribble, J.A.G. (1971). Functional comparative development trials – tool entrenching new design SCD/P759 and case tools entrenching. Army Personnel Research Establishment Memorandum 9/71.

[32] Gruber, A., Dunlap, J., Denittis, G., Sanders, J.L. and Perry, V.W. (1965). Development of a methodology for measuring infantry performance in digging hasty fighting positions. (Abstract only). Published on STINET reference AD Number: AD467159.

[33] Hansson, P.-A. and Öberg, K.E.T. (1996). Analysis of biomechanical load when shovelling. Journal of Agricultural Safety and Health, 2(3): 124-142.

[34] Human Effort. (1999). Job demands analysis – labourer: sewers. www.gvrd.bc.ca/labour/PJDA/PJDALabourerSewersBby.pdf

[35] Jamnik, V.K. and Gledhill. (1992). Development of fitness screening protocols for physically demanding occupations. *Can J Sports Sci,* 17: 222-227.

[36] Jorgensen, M.J., Davis, K.G., Kirking, B.C., Lewis, K.E.K. and Marras, W.S. (1999). Significance of biomechanical and physiological variables during the determination of maximum acceptable weight of lift. Ergonomics, 42(9):1216-1232.

[37] Knapik, J.J., Jones, B.H., Sharp, M.A., Darakjy, S., Jones, S., Hauret, K.G. and Piskator, G. (2004). *The case for pre-enlistment physical fitness testing: Research and recommendations.* USACHPPM Report Number 12-HF-01Q9D-04.

[38] Kommerell, B. (1929). Die Schauufelarbeit in gebűckter Haltung. *Arbeitsphysiologie*, 1: 278-295.

[39] Lee, S.W. (1992). Task-related aerobic and anaerobic physical fitness standards for Canadian Army. Edmonton Alberta, Canada, University of Alberta Dept of Physical Education and Sports Studies. PhD dissertation.

[40] Léger, L. and Gadourym, C. (1989). Validity of the 20 m shuttle run test with 1 minutes stages to predict VO_2max in adults. Canadian Journal of Sports Sciences, 14(1): 21-26.

[41] Lehmann, G. (1953). *Praktische Arbeitsphysiologie* (Stuttgart: Thieme).

[42] Marra, W.S., Lavender, S.A., Leurgans, S.E., Rajulu, S.L., Allread, W.G., Fathallah, F.A. and Ferguson, S.A. (1993). The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. Spine, 18: 617-628.

[43] McGorry, R.W., Dempsey, P.G. and Leamon, T.B. (2003). The effect of technique and shaft configuration in snow shovelling on physiologic, kinematic, kinetic and productivity variables. *Applied Ergonomics,* 34(3): 225-231.

[44] Military Engineering. (1993). Volume II Field Engineering, Pamphlet no. 2. Field Fortifications. Army code no 71271 (Pam 2).

[45] Military Engineering. (1996). Volume II Basic Field Engineering, Pamphlet no. 1. Part 2 Tools and Skills. Army Code No. 71601.

[46] Military Operational Medicine Research Program (MOMRP). (1999). Research Workshop on physical fitness standards and measurements within the military services. Proceedings of the workshop 31 Aug to 02 Sep 1999, Washington Dulles Airport Hilton, Herndon VA, USA.

[47] Montazer, M.A., Ruiz, R.G. and Sanders, M.S. (1989). Optimal position of D-handles on snow shovels. *Proceedings of the human factors society 33rd annual meeting.* pp. 486-489.

[48] Moss, K.N. (1923-24a). Some effects of high air temperature and muscular exertion upon colliers. *Transactions of the Institute of mining engineers (London),* 66: 284-314.

[49] Moss, K.N. (1923-24b). Some effects of high air temperature and muscular exertion upon colliers. *Proceedings of the Royal Society of London B,* 95: 181-200.

[50] Moss, K.N. (1934). The energy output of coal miners during work. Transactions of the Institute of mining engineers (London), 89: 132-149.

[51] Műller, E.A. and Karrasch, K. (1956). Die grősste Dauerleistung beim Schaufeln. *Internationale Zietschrift fűr angewandte Physiologie einschliesslich Arbeitsphysiologie,* 16: 318-324.

[52] Myers, D.C., Gebhardt, D.L., Crump, C.E. and Fleishman, E.A. (1984). Validation of the military entrance physical selection strength capacity test. USARIEM Technical Report 610, USA.

[53] National Institute for Occupational Safety and Health (NIOSH). (1981). Work practices guide for manual lifting, DHHS (NIOSH) Pub. No 81-122 (NIOSH, Cincinnati, Ohio, USA).

[54] NATO. (2001). Land Force Combat Engineer Doctrine ATP-52(A) (originally printed in January 1997) – (NATO UNCLASSIFIED).

[55] Nevola, V.R., Puxley, K.P., Messer, P.M., Roberts, A.J. and Collins, S.M. (2003a). Development of operationally-related physical fitness standards for the Royal Air Force (Phase 1 report). QinetiQ Technical Report QinetiQ/K1/CHS/TR030168, Farnborough, UK.

[56] Nevola, V.R., Coyles, V., Puxley, K.P. and Collins, S.M. (2003b). Development of operationally-related physical fitness standards for the Royal Air Force (Phase 2 report). QinetiQ Technical Report QinetiQ/K1/CHS/TR030169, Farnborough, UK.

[57] Öberg, K.E.T. (1993). The lumbar spine load during digging and shovelling with a magnum twin grip handle and an ordinary handle. Ergonomics of Manual Work, Taylor & Francis, London.

[58] Partridge, M. (1873) Farm tools through the ages (Boston: New York Graphic Society).

[59] Passmore, R. and Durnin, J.V.G.A. (1955). Human energy expenditure. Physiological reviews, 35: 801-840.

[60] Pradhan, C.K., Goswami, A., Ghosch, S.N. and Nag, P.K. (1987). Ergo-design and physiological evaluation of spade work. (presented at the Ergonomics in developing countries: An international Symposium). *Occupational Safety and Health*, 58: 436-444.

[61] Rayson, M.P., Wilkinson, D., Carter, J., Richmond, V. and Blacker, S. (2004a). Representative service tasks for the Royal Air Force – reliability protocols v1. Optimal Performance Limited technical report conducted on behalf of PTC RAF Innsworth, UK. (14 September).

[62] Rayson, M.P., Wilkinson, D., Carter, J., Richmond, V. and Blacker, S. (2004b). The reliability of the RAF's proposed representative service tasks. Optimal Performance Limited Customer report conducted on behalf of PTC RAF Innsworth, UK. (19 November).

[63] Sen, R.N. and Sahu, S. (1996). Ergonomic evaluation of a multipurpose shovel-cum-hoe for manual material handling. *International Journal of Industrial Ergonomics,* 17: 53-58.

[64] Sharp, M.A., Patton, J.F. and Vogel, J.A. (1998). A database of physically demanding tasks performed by US Army soldiers. T98-12, 1-42. Natick, MA, USA Army Research Institute of Environmental Medicine Technical Report. 3-10-0098.

[65] Singh, M., Lee, S.W., Chahal, P., Oseen, M. and Couture, R.T. (1991). Development of the Forces mobile command Army Physical Fitness standards for field units. Edmonton Alberta, Canada, University of Alberta Dept of Physical Education and Sports Studies.

[66] Snook, S.H. and Ciriello, V.M. (1991). The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics,* 34(9): 1197-1213.

[67] Sonoda, T. (1962). Studies on the compression, tension and torsion strength of the human vertebral column. *Journal of the Kyoto Prefecture and Medical University,* 71: 659-702.

[68] Spitzer, H. (1950). Die Rationelle Ausfũhrung der Korperarbeit. *Stahl und Eisen,* 70: 509-515.

[69] Stevenson, J.M., Bryant, J.T., Andrews, G.M., Smith, J.T., French, S.L., Thomson, J.M. and Deakin, J.M. (1992). Development of physical fitness standards for Canadian Armed forces younger personnel. *Can J Sports Sci,* 17: 214-221.

[70] Stickland, A. (1995). Field defences – trench construction and alternatives. Defence Research Agency report number DRA/FV&S6/CR95/078/1.0.

[71] Taylor, F.W. (1913). The principles of scientific management. (New York: Harper & Bro).

[72] Tharion, W.J., Lieberman, H.R., Montain, S.J., Young, A.J., Baker-Fulco, C.J., DeLany, J.P. and Hoyt, R.W. (2005). Energy requirements of military personnel. *Appetite,* 44: 47-65.

[73] TNC Fire. (2000). Measuring your physical fitness – a PowerPoint presentation by the Nature Conservancy Organisation, USA. http://tncfire.org/resource/fitness3.ppt

[74] Van der Grinten, M. (1987). Shovel design and back load in digging trenches. *Musculoskeletal disorders at work* (Ed) P Buckle, pp. 96-101.

[75] Vennewald, H. (1939). Ű̃ber die Zweckmässigkeit der Grabwerkzeugen. *Arbeitsphysiologie,* 10: 647-667.

[76] Vogel, J.A.., Wright, J.E. and Patton, J.F. (1980). A system for establishing occupationally-related gender-free physical fitness standards. USARIEM technical report no. T5/80 (AD AO94518).

[77] Visser, T., Dijk, J., van der Doelen, L.H.M. and Veenstra, B.J. (1996). Physiological aspects of the military task digging. LTG Knoop Barracks, Utrecht, Netherlands: Training Medicine and Training Physiology, Team/NATCO. TGTF Report No. 96-106.

[78] Walker, K. (1979). Entrenching tool hand. Infantry trials and development unit, trial report. TD/MISC/2 (14 September).

[79] Wenzig, K. (1928). Arbeitsphysiologische Studien. VII, Beiträge zur Physiologie des Schaufelns. *Arbeitsphysiologie,* 1: 154-186.

[80] Wenzig, K. (1932). Arbeitsphysiologische Studien. X, Beiträge zur Physiologie des Schaufelns. *Arbeitsphysiologie,* 5: 252-268.

[81] Wilson, J.R. and Corlett, E.N. (1995). Evaluation of human work: a practical ergonomics methodology. Taylor & Francis, London, UK.

[82] Wright, S.A. (1993). An improved Infantry digging tool. Thesis submitted in part fulfilment of the award of MSc from the Royal Military College of Science, Cranfield Institute of Technology.

Appendix 4A-1

Summary of Digging Methods Used by the British Army for Specific Material Types (Taken from Wright 1993).

Group	Types of rocks and soils	Suggested **digging methods**
Rocks	• Hard igneous and gneissic rocks • Hard limestones and hard sandstones • **Schists and slates** • Hard shales, hard mudstone and soft sandstone • **Soft shales and soft mudstone** • Hard sound chalk and soft limestone • **Thinly bedded limestones, sandstones and shales** • **Heavily shattered rocks**	• Explosive • Explosive • **Pick / spade** • Explosive • **Pick / spade** • Explosive • **Pick / spade** • **Pick / spade**
Non-cohesive soils	• **Compact gravel, or compact sand and gravel** • **Medium dense gravel or medium dense sand and gravel** • **Loose gravel, loose sand and gravel** • **Compact sand** • **Medium dense sand** • **Loose sand**	• Explosive / **pick** • **Pick / spade** • **Pick / spade** • **Pick / spade** • **Pick / spade** • **Spade**
Cohesive soils	• **Very stiff boulder clays and hard clays** • **Stiff clays** • **Firm clays** • **Soft clays and silts** • **Very soft clays and silts**	• Explosive / **pick** • **Pick / spade** • **Pick / spade** • **Spade** • **Spade**

Appendix 4A-2

Entrenchment Dig Protocol for Canadian Forces Personnel: Minimum Physical Fitness Standards 2000 (Taken from Deakin et al., 2000b).

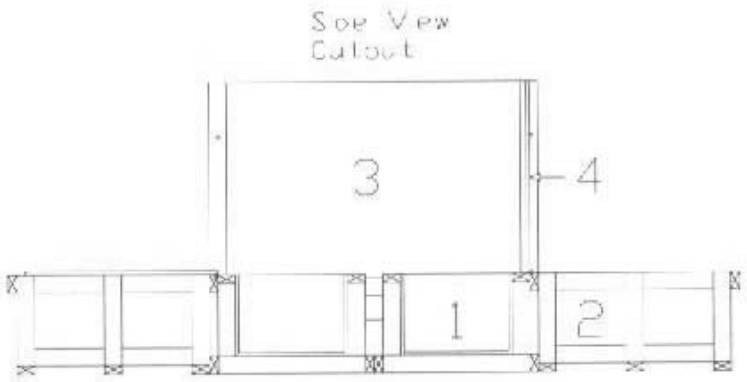
ENTRENCHMENT DIG

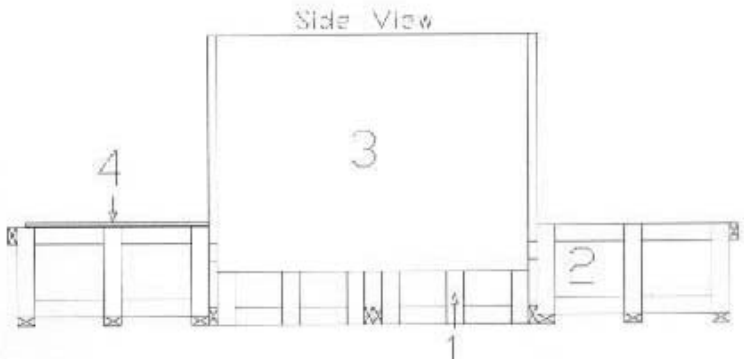
Introduction

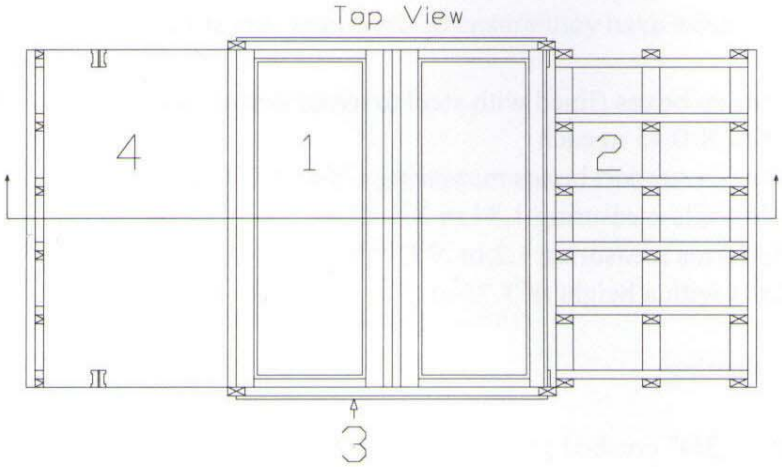
The Entrenchment Dig consists of two boxes to contain the gravel (1), two suppor boxes (2), two side walls (3), and two hinged platforms (4). Prior to testing, one of the sa boxes, measuring 1.8 m x 0.6 m x 0.45 m, is filled with gravel and leveled off.

This task requires the subject to dig out one of the boxes until there is less than on shovel full left in the box. The time required to dig the box will be recorded.

Assembly






Top View
4
1
2
3

Equipment

- Two wooden boxes (lined with steel to avoid destruction of the bottom) measuring 1.8 m X 0.6 m X 0.45 m each
- Two wooden support boxes measuring 1.8 m X 0.6 m X 0.45 m each
- Two side walls measuring 1.84 m X 1.22 m
- Two platforms measuring 1.2 m X 1.95 m
- Four 2X4s with a height of 1.75 m
- Nails
- Rubber matting
- Stain
- Gravel: 3/4" crushed gravel (Trenton); Pea stone (Petawawa, Halifax)

Set up

1. Place the two entrenchment boxes side by side so that the hinged sides open outward from them.
2. Place one support box under the hinged side of each box. Nail each support box to the entrenchment box beside it.
3. Secure the two entrenchment boxes by nailing the 2X4s along the width of both boxes. These 2X4s should form a ledge at a height of 0.6 m.
4. Screw the side walls into the 2X4 wood braces. Do this in a manner such that the holes in the side walls accommodate the sliding bolts in the hinged end pieces of the platform.
5. To prevent gravel form sliding through the cracks, rubber flooring should be stapled to cover any exposed joints.

Maintenance

Daily Maintenance:

1. Check side walls to ensure they are not loose
2. Check wooden platform on which subjects stand to ensure no sign of cracks or failure
3. Check moisture of gravel and add water if needed for consistency.
4. Check the level of gravel and add more until the box is leveled off.

Weekly Maintenance:

1. Clear out any gravel that has become wedged underneath the rubber matting. This may have to be done periodically during the testing session.
2. Check the interior/exterior of the boxes to see if any bowing or splitting of the wooden containers is occurring. Repair as needed.
3. Check the metal liners of the boxes to ensure a tight fit and no gravel has collected beneath the liner.

4. Check the 2X4's supporting the side guardrails to ensure they have not become loose from people leaning on them.

Daily Set Up

Gather the following equipment:

3 shovels: (1.5m high, spade surface area 28cmX 22cm)
gloves
1 stop watch
3 heart rate monitors
water (for HR monitors)
clip boards
towel
2 stable brooms, 1 corn broom
pens

ENTRENCHMENT DIG PROTOCOL

Introduction

The purpose of this task is to dig a trench, measuring 1.8 m X 0.6 m X 0.45 m, as quickly as possible.

The tester is responsible for starting the test with the "go" command and, once the box has been emptied, stopping the test with the command "stop". The tester will record the time taken for the subject to complete the task.

The tester should remind the subject that there is no sitting allowed while digging. The subjects may kneel on the ledge between the boxes or in the box they are digging. It is recommended that subjects start by straddling the box.

Near the completion of the test, it is recommended that subjects use the sides of their feet or their gloved hands, as well as the shovel in a sweeping action.

Instructions to Subjects

The tester will read the following instructions:

1. This task is a simulation of a one-person foxhole dig.
2. You will clear the box, as fast as possible, pitching the crushed rock into the other box.
3. You will start digging on the command "go".
4. (Demonstrate shovel hold and digging technique).
5. The test will end when you are given the command "stop".
6. If you feel that you have reached the end point before being told to stop, you should use the shovel in a "sweeping" action to gather the gravel into piles and continue clearing the box. (Show subject the empty box to demonstrate the end result).
7. Gloves are provided.
8. If you feel this task is too demanding, it may be terminated at any time.
9. Are there any questions?

Appendix 4A-3

Two-man Battle Trench (Taken from Military Engineering Volume Ii Field Engineering Pamphlet No 2 – Field Fortifications, Army Code No. 71271 (Pam 2)).

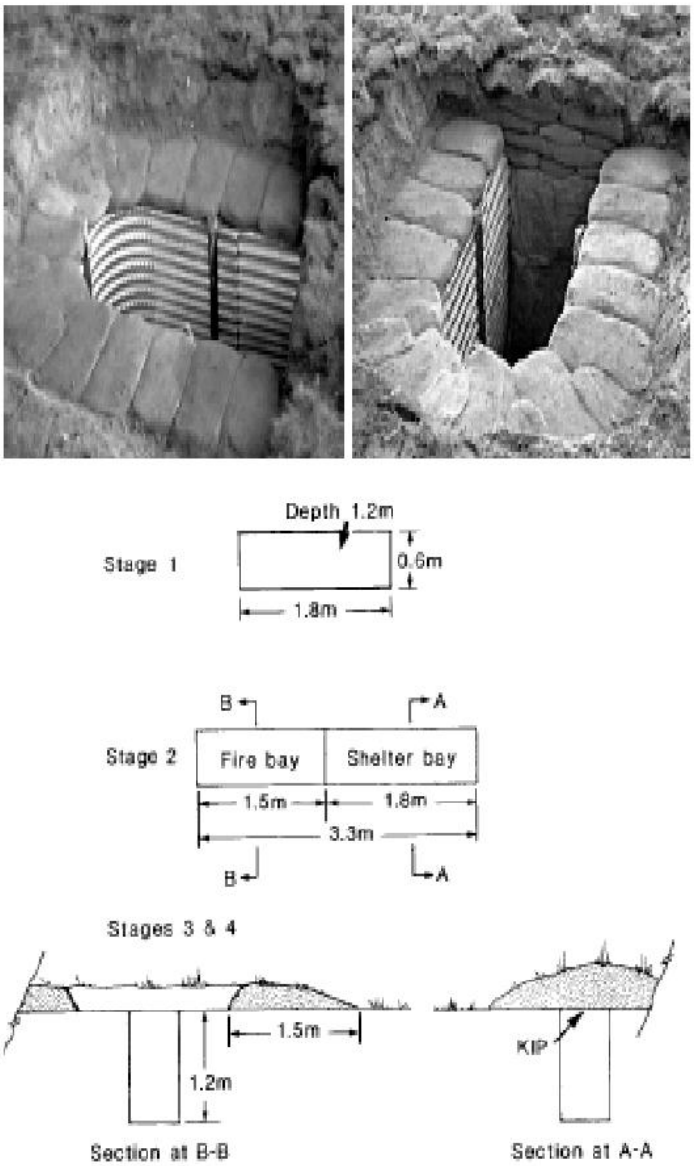


Figure 4A-3-1: Two-Man Battle Trench (One Type that Has Been Used by the British Army).

There are several types of two-man battle trench that are used by military services throughout NATO. Army code no.71271 (Pamphlet 2) 1993 (British Army) specifies the need to use 12 to 24 sandbags, and that all excavation (to the dimensions illustrated in Figure 4A-3-1) conducted by hand using an entrenching tool hand, pick axe and shovel. Approximately 0.45 m depth of material is shovelled and 'compacted[70]' on top of the shelter area within the trench.

[70] The process of compacting material involves striking the material with the blunt aspect of the digging tool or shovel until the material is sufficiently reinforced to avoid noticeable movement underfoot.

Appendix 4A-4

Four-man Battle Trench (Taken from Military Engineering Volume II Field Engineering Pamphlet No 2 – Field Fortifications, Army Code No. 71271 (Pam 2)).

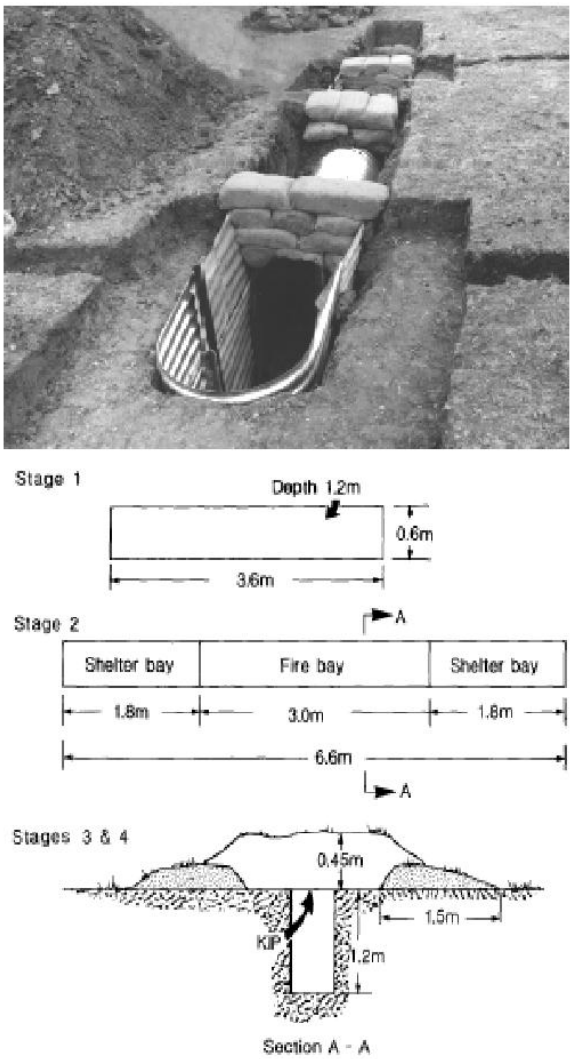


Figure 4A-4-1: Four-Man Battle Trench (One Type that Has Been Used by the British Army).

There are several types of four-man battle trench that are used by military services throughout NATO. Army code no.71271 (Pamphlet 2) 1993 (British Army) specifies the need to use 45 to 110 sandbags, and that all excavation (to the dimensions illustrated in Figure 4A-3-1) conducted by hand using an entrenching tool hand, pick axe and shovel. Approximately 0.45 m depth of material is shovelled and 'compacted[71]' on top of the shelter area within the trench.

[71] The process of compacting material involves striking the material with the blunt aspect of the digging tool or shovel until the material is sufficiently reinforced to avoid noticeable movement underfoot.

Appendix 4A-5

Modified Protocol for the Royal Air Force Representative Service Task (RST) 'Digging'.

4A-5.1 RST 4 – DIGGING

4A-5.1.1 Aim

To confirm the strength and endurance of the muscles required to shovel 0.25 m^3 of pea shingle (10 mm stone) through a 22 cm radius round hole set into a barrier at a height of 1.1 – 1.3 m (upper and lower arms, shoulder girdle, torso (especially back extensors) and legs). This task represents 2 COTs: digging a slit trench and building a sandbag sangar; and sandbagging. The volume of 0.25 m^3 represents the amount of earth/sand that must be shovelled to fill 10 sandbags. During operations, filling sandbags and digging a slit trench may need to be performed as quickly as possible, which is the rationale behind the task. The height of the hole in the barrier (1.1 – 1.3 m) has been introduced as when filling sandbags the shovel is lifted to around 1.2 m if the sandbags are held fully upright (Rayson MP and Wilkinson DM, 2002) and when constructing a trench or sandbag sangar the earth must be moved up and out of the trench a variable height depending on the depth of the trench. A height of 1.1 – 1.3 m provides a reasonable representation of these variable, heights of lift of the shovel. The hole has since been introduced to ensure standardised technique (stopping people flicking shingle over) and to better reflect the task of sandbagging.

4A-5.1.2 Test Overview

The test should be conducted in groups of up to 6 personnel and consists of shovelling 0.25 m^3 of pea shingle with a spade through a hole set into a barrier at a height of 1 – 1.3 m in the fastest possible time.

4A-5.1.3 Procedure

4A-5.1.3.1 Practice

Personnel should be briefed and shown a demonstration of how to shovel the pea shingle according to the coaching points (4). Each person should then be allowed 5 practice shovels in accordance with the test protocol (3.2), to familiarise themselves with the techniques and to select a sustainable work rate.

4A-5.1.3.2 Test

Personnel must stand in the box at all times, on top of the gravel initially. Using the spade provided, the gravel should be moved from the first to the second box as quickly as possible.

4A-5.1.4 Coaching Points

- The gravel may be moved using any style, provided that the spade is used to move the gravel through the hole into the second box and that the personnel stand within the dimensions of the box.
- Personnel should be provided with the following coaching points by the Instructor (this is advice only and other methods can be used):
  - Demonstrate how to hold the spade and dig into the pea shingle.
  - Show personnel they can kneel in the box while shovelling to ease possible back strain.
  - Emphasise that the shovel must either pass through the hole or touch the barrier when transferring the gravel into the second box, i.e. the shovel cannot be flicked through the hole whilst standing at the back of the box.

  - Indicate that when the gravel level gets lower they can drag the gravel to the front end of the box, to pile it up.
  - When the box is almost empty they can scrape remaining pea shingle to the corner to dig it out.
- Personnel may rest at any time during the test. Personnel must also be briefed that they may withdraw from the test at any stage if:
  - They feel they can not safely start the digging task.
  - They feel they are not capable of finishing the digging task (moving the 0.25 m^3 of gravel).

4A-5.1.5 Dress

Boots, t-shirt, combat jacket (with sleeves rolled down), combat trousers, helmet and black gloves. weapon and webbing?

4A-5.1.6 Equipment

A purpose built digging box internal dimensions 1.15 x 0.87 x 0.25 m, with a 0.20 m diameter hole set into a 1.5 m high barrier at a height of 1.1 – 1.3 m.

- At least 0.4 m^3 of gravel for each box used.
- Data recording sheets.
- Stopwatch to time the digging test.
- Spade (0.72 m long and a blade of 0.19 x 0.23 m).

4A-5.1.7 Test Layout

See Figure 4-13: The modified (v2) protocol for the Representative Service Task digging conducted during the assessment of 'repeatability' by Rayson et al., 2004a.

4A-5.1.8 Recovery

After the test personnel will complete a PTI-led cool down period (approximately 5 min) of low intensity activity (e.g. walking and stretching) as this is the end of the RST tests.

4A-5.1.9 Failures

Personnel who fail to move the 0.25 m^3 of gravel from one box to the other, or personnel who self withdraw or the administrator stops the test for safety reasons.

4A-5.1.10 Data Recording

The result to be recorded is the time taken to complete the task in minutes and seconds, e.g. 3:45 mins.

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